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A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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W. H. TWENHOFEL, EDITOR

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal*, should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 10, NO. 1, PP. 3–4, APRIL, 1940

THE TENTH VOLUME

W. H. TWENHOFEL

With this number the *Journal of Sedimentary Petrology* begins its tenth year. It was founded in 1931 by the Society of Economic Paleontologists and mineralogists and was intended as a journal in which the Society could publish articles that did not deal with paleontology and articles which could not properly appear in the Society's *Journal of Paleontology*, a journal of little service to those members of the Society who were not paleontologists. It was intended that the *Journal of Sedimentary Petrology* should contain articles dealing with the constitution of sediments, but that processes concerned with the deposition of sediments should be little emphasized, and that the medium of publication for such articles should be the *Bulletin of the American Association of Petroleum Geologists*. There has been rather close adherence to this policy.

The first editor of the *Journal of Sedimentary Petrology* was Prof. Raymond C. Moore of the University of Kansas. This was fitting as its founding was largely due to his initiative. The first volume, published in 1931, consisted of two numbers totaling 101 pages of printed matter with 12 articles. The numbers were issued in May and November. The second volume, that of 1932, contained three numbers with an increase in printed pages to 167. Since 1932, the volume for each year has consisted of three numbers.

The literary editorship of the *Journal* was relinquished by Prof. Moore early in 1933 to Prof. W. H. Twenhofel of the University of Wisconsin, but Prof. Moore was persuaded to retain managing editorship. This arrangement continued until the middle of 1939 when Professor Moore requested that he be relieved of the responsibility of the managing editorship, and his duties were assumed by the present editor.

The first board of editors consisted of Prof. Moore and the associate editors, Dr. P. G. H. Bosworth and Dr. Henry B. Milner of London, England; Dr. Clarence S. Ross of the U. S. Geological Survey, Washington, D. C., Dr. Marcus A. Hanna of Houston, Tex., Prof. A. C. Trowbridge of Iowa City, Ia., Dr. Ralph D. Reed of Los Angeles, Calif., and the present editor. Prof. Allen C. Tester of the University of Iowa was added to the board in 1932. The board, as thus constituted, remained until 1936 except in 1933, when Prof. Moore became managing editor and Prof. Twenhofel, editor. In 1936, Dr. Bosworth and Prof. Trowbridge retired from the board of associate editors, and Prof. W. C. Krumbein of the University of Chicago was appointed. Prof. Tester retired from the board in the middle of 1938, and his place was taken by Prof. R. Dana Russell of the University of Louisiana. No subsequent changes have been made.

During the last nine years the *Journal* has published 1226 printed pages exclusive of announcement pages and there have been 130 articles written by over 100 authors. Most articles have dealt with the physical, chemical, mineralogical and petrographical characteristics of sediments and sedimentary rocks. Many articles have discussed methods of study and others have presented statistical studies of various features of sediments. Several new techniques of study have been published. The publications have been a credit to the *Journal*.

Attempt has been made to publish timely articles and to maintain the *Journal* in line with progress. Members of the Society of Economic Paleontologists and Mineralogists, particularly the younger men, have been encouraged to submit manuscripts which have been favored for early publi-

cation. However, members of the Society have not furnished sufficient material to fill the *Journal* and thus many manuscripts have been acquired from writers who had no connection with the Society. These writers have been urged to become members. Receipt of manuscripts from young as well as experienced writers has placed much work on the shoulders of the editor as many manuscripts have had to be returned for rewriting. In some cases, this has had to be done several times. With few exceptions, the writers have been very grateful for this assistance and the editor feels that many friendships have been made by the procedure.

The editor cannot refrain from giving directions. Authors submitting manuscripts for publication should always carefully study these to see that presentation is logical and sequential and that statements are made in the fewest possible words consistent with clearness of expression. All extraneous material should be omitted and every word should count toward the objective of the paper. *Each article must have an abstract.* All references should be terminal and should be arranged in order as follows: author, date of publication, title of article, name of medium of publication, volume and pages.

Footnotes should not be confused with references. When necessary to use a footnote in the manuscript, the author should use superior figures in text indicating them by a "shelf" (^{1}) at each reference. Footnotes are numbered consecutively and are single-spaced. The items in a footnote should be written immediately below the citation in the text and set off above and below from the text material by line rules.

The writer has watched the progress of sediment study for over 30 years. He recalls his course in petrography at Yale University under a kindly and most excellent teacher, Prof. L. V. Pirsson, when in a course of one year, essentially no attention was given to sediments or sedimentary rocks. The early studies of Dr. J. A. Udden and later those of Dr. M. I. Goldman are remembered. And then to enter a modern sedimentation laboratory! A place for chemical studies, a heavy mineral laboratory, apparatus for studies of transportation of sediments, an X-ray laboratory, precision instruments for measurement of dimensions and other physical features of sediments, and suites of both binocular and petrographic microscopes! If one, like Rip van Winkle, could have slept and not have seen the progress between 1910 and 1940, and on his awakening saw the change, he certainly would have cause to marvel at the progress that had been made. He would say, following Pope, that:

New techniques teach new duties.
Time has made ancient good uncouth (and he would inevitably be forced to the decision that)
Let us then be up and doing.
That we keep abreast of truth.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 10, NO. 1, PP. 5–7, FIG. 1, TABLE 1,
APRIL, 1940

MINERAL STUDY OF SANTA ROSA SANDSTONE IN GUADALUPE COUNTY, NEW MEXICO

RAYMOND SIDWELL and DONALD GIBSON
Texas Technological College, Lubbock, Texas

ABSTRACT

The Santa Rosa sandstone of Guadalupe County, New Mexico, has a maximum thickness of 70 feet. The upper and middle portions are exposed near Santa Rosa and the basal beds near Dilia. The abundant minerals are magnetite, ilmenite, garnet, tourmaline, hematite, olivene, rutile, zircon, quartz, biotite, and muscovite.

INTRODUCTION

Guadalupe County lies in the east central part of the state of New Mexico, and the greater portion is embraced in the Pecos section of the Great Plains Province. The extreme southwestern portion of the county lies within the Mexican Tableland, a division corresponding in rank to the Great Plains Province to the east.

In general, this region is expansive with gentle slopes toward the Pecos River and its tributaries. In this rolling plain are numerous mesas and buttes, many of which are capped with one or more members of the Dockum group of the Triassic. To the northwest and northeast of the city of Santa Rosa, the rocks dip gently eastward. The relief of the area is characteristically that of a land of little rain and the facial expression of the region is due to stream and wind erosion.

METHOD OF PROCEDURE

Numerous samples for laboratory study were collected. These samples represent a vertical cross section of the outcrop. In the laboratory, 30 grams of each sample were selected and the calcareous cement was removed in dilute hydrochloric acid. The material was washed to remove the acid, dried, and then sieved to secure the individual grain sizes. The heavy minerals were removed by the use of bromoform, and separated into magnetic and non-magnetic groups. These minerals were identified and the abundance of each determined.

DESCRIPTION OF THE SANDSTONE

The Santa Rosa sandstone is a member of the Dockum group of the Triassic and was named from the exposure in the railroad cut about one mile east of the town of Santa Rosa, New Mexico. Other exposures are on the Pecos River north of Santa Rosa near Colonias, Anton Chico, and Dilia, in the southwestern corner of the county near Vaughn. This sandstone is also present a few miles west of Montoya near the eastern edge of the county. The lower beds of the Santa Rosa sandstone are exposed near Dilia and overlie gypsum and shale which are probably of Permian age. The middle and upper beds outcrop near Santa Rosa.

Santa Rosa sandstone is compact, crossbedded, of variegated colors such as gray, red, buff and purple, and in a complete section has a thickness of about 70 feet. Two thin conglomeratic layers are present; one is about 15 feet from the base and contains clay balls; the other is about 20 feet from the top and marks the base of a compact sandstone layer.

Minerals of Santa Rosa sandstone.—The amount of wear and the relative abundance of both light and heavy minerals were determined. The light minerals have a specific gravity less than 2.9. These consist of quartz, muscovite and

biotite. The heavy minerals are magnetite; ilmenite; garnet; rose, green, black and blue tourmaline; hematite; olivine; rutile; and purple, transparent and brown zircon.

The magnetite is steel gray or black. The majority of the grains are fragmental and irregularly fractured; however, a small percentage is rounded. Most of the magnetite particles are less than $\frac{1}{4}$ mm. in diameter. This mineral is present throughout the formation, but the greatest concentrations are about 8 feet above the base, near the middle of the formation, and a few feet from the top. Magnetite is not abundant in the light colored sandstone layers.

The ilmenite commonly occurs as irregular, subangular grains, which in some cases, have a characteristic purple-gray luster in reflected light. Ilmenite is not abundant and is found associated with magnetite, chiefly in the dark colored layers.

FIG. 1.—Map showing the location of the Santa Rosa sandstone.

Two varieties of garnet are present, deep red pyrope and pale pink almandine. It is present chiefly as irregular grains. Garnet is concentrated near the top of the formation.

Rose, green, black and blue tourmalines are present. The green and black varieties are the most abundant. Some of the green variety is in the form of hexagonal prisms with well developed crystal faces.

TABLE 1. *Showing the abundance, in numbers, of the heavy minerals in 30 grams of sand*

		Distance in Feet From Base						
		−10	10–20	20–30	30–40	40–50	50–60	60+
Magnetite		29	128	45	570	425	84	800
Ilmenite			6			20		90
Garnet		6	2		21	10	18	40
Tourmaline	Rose	2	4	2	23		30	80
	Green	115	55	11	20	25	8	6
	Black	93	22	16	17	46	7	50
	Blue	4	4	2	8		2	
Hematite		600	26	110	80	268	36	200
Olivine					100			
Rutile		20	18	5	11	11	7	27
Zircon	Purple	47	43	15	40	15	40	40
	Trans.	23	26	10	28	7	10	35
	Brown	20	15	3	19			12

Most of the rose, black and blue varieties are in the form of irregular grains with smooth rounded surfaces. All varieties occur throughout the formation but are most common in the lower layers.

The hematite is dark reddish-brown by reflected light, and it has a dull to submetallic luster. The mineral exhibits irregular fracture and some flat particles show well rounded edges. Hematite is concentrated in the dark colored layers of the middle and upper part of the formation.

Olivine is present only near the middle of the formation. The grains are irregular and many are fractured. Traces of decomposition are present on some grains. The color varies from dark green to yellowish green.

The rutile is reddish-brown with a vitrous to resinous luster. Most particles are elongated, tabular and subangular fragments. This mineral is not abundant but is present throughout the formation.

Most zircon particles are smaller than $\frac{1}{8}$ mm. in diameter. The purple and transparent varieties are abundant; the brown type is rare. Most perfect prismatic crystals with pyramidal terminations were found. Fragmentary grains are well rounded. Zircon is abundant in the lower layers and also near the top of the formation.

Quartz is the abundant light mineral. In the light colored layers it is transparent, but in the dark colored beds many particles have brown, yellow and red iron coatings. The majority of the grains are angular with rounded edges, but some have crystal faces.

Both muscovite and biotite are abundant and these minerals may be seen in hand specimens. The minerals occur as flakes with average diameter of about 2 mm. The color of the biotite varies from black with bright luster to greenish black with dull luster. Some of the greenish black biotite has a specific gravity greater than 2.8. Many of the muscovite flakes contain zircon inclusions.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 10, NO. 1, PP. 8–11, FIG. 1, TABLE 1, APRIL, 1940

NOTES ON THE MINERAL ASSEMBLAGE OF THE "WHITE SILT" TERRACES IN THE OKANAGAN VALLEY, BRITISH COLUMBIA

CHARLES MEYER and KEITH YENNE
Washington University, St. Louis, Missouri

ABSTRACT

Mechanical screen and pipette analyses and study of the heavy mineral assemblages of samples of the "white silt" deposits of the Okanagan Valley, British Columbia, support the conclusions of Daly and Flint that these sediments represent accumulations of rock flour at or near the mouths of streams emptying into the ice-dammed lakes which occupied the valley at the close of the Pleistocene.

INTRODUCTION

Earliest reference to the "white silts" of the Okanagan Valley, British Columbia, was made in 1879 by Dawson, who at that time considered them to be the lacustrine deposits of glacier-fed streams. Later, however, in 1896, the wide distribution and uniform elevation of the terraces and the lack of typically associated glacial deposits led him to regard them as marine. More recent study of similar material in the South Thompson Valley and consideration of the present elevated position (2000 feet) of these deposits convinced Daly (1915) that the terraces were lacustrine in origin and Pleistocene in age. In 1935, Flint published a detailed account of the field relations of the Okanagan "white silts" in which he attributed them to deposition in an ice-dammed lake occupying the Okanagan trench during the melting of the ice sheet at the close of the Pleistocene.

The writers are indebted to Dr. Carl Tolman of Washington University for collection of samples, use of unpublished notes and maps, and general supervision of the preparation of the present paper.

FIELD RELATIONS

According to Flint the silt terraces are widest near the mouths of tributary streams emptying into Skaha Lake and the southern half of Okanagan Lake.

Stratification is typically well developed, but individual beds range from minute laminations, present in broad flat terraces like those on the northeast shore of Skaha Lake, to massive beds several feet in thickness which were deposited closer to the relatively steep valley walls.

Flint also points out that, in addition to stratification, lateral gradations to sand and gravel are prominent, especially in the upper layers of the silt near the mouths of large tributary streams. Local severe contortions of the bedding planes of the silt are regarded by Flint as "sag-complexes" which resulted from the melting of buried ice blocks with consequent slumping of the overlying deposits.

PETROGRAPHY

Four representative samples were studied; three from the terraces flanking to the north shore of Skaha Lake in the Okanagan Valley, and one from the terrace in the Mission Creek Valley several miles east of Okanagan Lake, British Columbia. All of them are light gray to light buff in color and characterized by a relatively fine flour-like texture.

After routine screen and pipette mechanical analyses the fractions of the samples between 1/16 mm. and $\frac{1}{8}$ mm. were separated by the use of bromoform (sp. gr. 2.88), and an electromagnetic division of the heavies into two groups was effected to facilitate identification of the minerals. Vigorous effervescence and a 15

per cent average decrease in weight during preliminary acid treatment indicated the presence of an appreciable amount of calcite, probably derived from leaching of the surrounding rocks.

In three of the samples, the fraction less than 1/16 mm. is by far the largest, whereas in the fourth the size greater than 1/16 mm. and less than ¼ mm. predominates. Both the massively stratified and laminated sediments are well sorted, though the peakedness of the frequency curve of the latter is somewhat more pronounced (fig. 1). The cumulative curve of the thickly bedded material, and to a lesser extent also that of the laminated silt, shows a skewness comparable to that determined for loess but the genetic implications of this relationship are as yet obscure. It may be suggested, however, that it seems probable that the finer grains present would have been removed if the sediments had been subjected to extensive fluviation before deposition. Furthermore, with the exception of a few of the less resistant minerals and several well rounded reworked grains, all of the particles are strikingly angular, some lath-shaped particles having an index of elongation exceeding 10.

Quantitative microscopic study of the light minerals greater than 1/16 mm. in diameter revealed about equal amounts of quartz and feldspar, and approximately one-third of the latter exhibited good plagioclase twinning. A few particles of microcline were also noted. Incipient kaolinization imparts a clouded appearance to many of the feldspar particles, though some still retain angular shape and clear-cut extinction. About 10 per cent of the material consists of unidentified aggregates, finely crystalline rock fragments, and a few grains of volcanic glass. Contrasting in composition with these Okanagan sediments are the silts of the

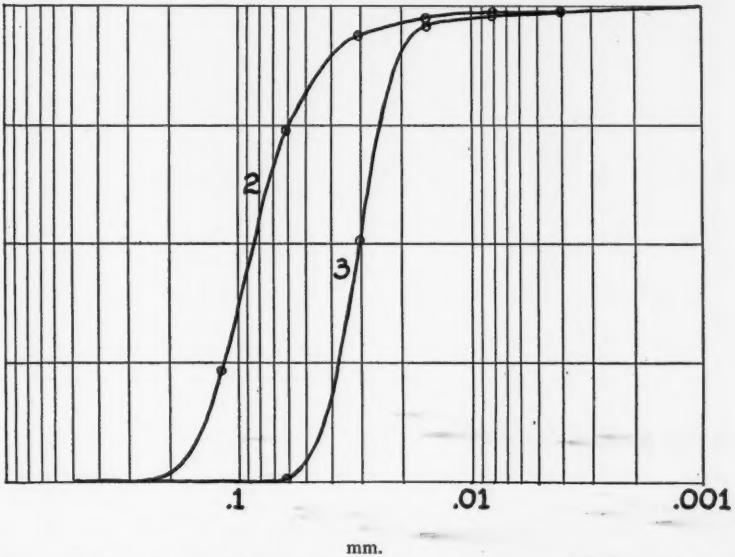

FIG. 1.—Cumulative curves of the mechanical analyses of silts no. 2 (thickly-bedded) and no. 3 (laminated) from the Okanagan Valley, British Columbia.

TABLE 1. *Heavy mineral frequency*

	Sample Number 1	2	3	4
Aegirine-augite	VR	VR	VR	VR
Augite	R	R	R	R
Diopside	C	C	C	C
Enstatite	R	R	R	R
Basaltic Hornblende	R	VR	VR	VR
Hornblende (colorless)	R	R	VR	A
(fibrous)	R	VR	VR	R
(X=yell., Y=bl.-gr., Z=gr.-bl.)	R	R	R	R
(common, green to brown)	VA	VA	VA	VA
Olivine	VR	VR	VR	VR
Garnet (pink)	R	R	VR	VR
(colorless)	C	R	R	R
Zircon	R	VR	VR	VR
Kyanite	VR	R	VR	VR
Tourmaline	VR	VR	VR	VR
Epidote-zoisite	VA	VA	VA	A
Muscovite	R	C	C	VR
Biotite (brown)	R	C	C	R
(green)	VR	R	R	R
Titanite	R	R	R	R
Apatite	VR	VR	VR	VR
Fluorite	VR	VR	VR	VR
Rutile				VR
Leucoxene	VR	VR	VR	VR
Sulfides (chiefly pyrite)	C	R	R	R
Hematite	R	R	VR	VR
Magnetite	C	R	R	R
Glass	R	C	VR	VR

VR Very rare 1 per cent or less of total heavies
R Rare 1 to 5 per cent or less of total heavies
C Common 5 to 10 per cent or less of total heavies
A Abundant 10 to 20 per cent or less of total heavies
VA Very abundant 20 per cent or more of total heavies

Sample no. 1. Disintegrated white silt from the northeast corner of Shaka Lake.
2. Silt from the northwest corner of Skaha Lake.
3. Finely stratified silt from the northeast corner of Skaha Lake.
4. Silt from the Mission Creek terraces, several miles east of Okanagan Lake.

South Thompson Valley 50 miles to the northwest, which were described by Daly as predominently feldspathic and low (18 per cent) in quartz.

Heavy minerals are most abundant in the fraction between 1/16 mm. and $\frac{1}{8}$ mm., averaging 5 per cent of the total weight in this size group in the samples from the north shore of Skaha Lake, and 10 per cent in the silt from Mission Creek. Hence, further contrast with the South Thompson silts is afforded by the rarity of dark-colored grains noted by Daly in these sediments as compared to the relative abundance of ferro-magnesian minerals in the Okanagan terraces.

The heavy assemblage is primarily characterized by a striking diversity of mineral species, as indicated in table 1, though hornblende and epidote-zoisite alone constitute three-fourths of the total. As may be expected, individual variations in each mineral species are common. Because of a continuous gradation in color (clear yellowish-green to nearly opaque white) a sharp distinction between epidote and zoisite is impractical, and the group is considered as a unit in the mineral frequency table. There are few dark-colored, zoned flakes of biotite and bits of yellow and green volcanic glass which bear hexagonally arranged crystallites and other inclusions.

SUMMARY AND CONCLUSIONS

Because of their field relations, particularly the local variations in thickness of beds, the presence of "sag-complexes" and of lateral gradation to sand and gravels, the "white silts" of the Okanagan Valley were considered by Flint to be Pleistocene lake deposits. As indicated in table 1, divergences from a petrographic norm for the silts of the entire Okanagan Valley are few, but at the same time, as already pointed out, there are distinctive mineralogical differences between the Okanagan sediments and those of the South Thompson Valley described by Daly. It would appear that these distinctions, in addition to the presence of very fine rock flour which would have been removed had the silts undergone much fluviation, are sufficient to confirm the conclusions of both Daly and Flint that they are of relatively local derivation and probably represent a lacustrine concentration of Pleistocene rock flour. The extreme angularity of grain outline and the occurrence of perishable feldspars and ferro-magnesian minerals, especially olivine, also indicate deposition after only a small amount of stream transportation.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 10, NO. 1, PP. 12–18, FIGS. 1–2, TABLE 1, APRIL, 1940

AUTHIGENIC ALBITE FROM THE LOWVILLE LIMESTONE AT BELLEFONTE, PENNSYLVANIA

ARTHUR P. HONESS and CHARLES D. JEFFRIES
Pennsylvania State College, State College, Pennsylvania

ABSTRACT

Insoluble residues, obtained from the Lowville limestone at Bellefonte, Pa., show appreciable quantities of authigenic albite of unusual purity. The mineral occurs as twinned idiomorphic crystals, the largest of which are about one-fourth millimeter along the major diameter. Inclusions of small rhombs and granules of calcite are commonly observed in the albite crystals. The authigenic character of the albite is suggested by the unusual chemical composition, idiomorphic habit, the dearth of associated clastic materials, and the manner of distribution in the limestone. The crystals do not appear to be confined to special horizons, nor are they related genetically to fracture zones which may be considered avenues of circulation for hydrothermal solutions. The enclosing rock shows no trace of metasomatic change or heat effects of any kind, nor do the crystals appear to show replacement features, but rather they suggest formation in the calcareous muds of the sea floor during deposition and compaction of the sediment. Complete chemical analyses of the feldspar collected at random from several different parts of the Lowville rock show no potash but an unusually high soda content.

Some years ago,[1] while making a petrographic examination of the Lowville limestone at Bellefonte, Pa., attention was directed to the presence of many small well-formed crystals occurring with quartz in the insoluble residues of the rock. A careful study of this material showed it to be a surprisingly pure form of albite. It was not possible at the time to make a thorough study of the albite occurrence, and further examination of the crystals was discontinued. During recent months the quarry rock at Bellefonte was resampled by the present writers, and the study of carefully prepared residues resumed.

The writers are pleased to acknowledge the helpful suggestions of Dr. William M. Meyers and Dr. Paul Krynine with whom this paper has been discussed.

OCCURRENCE AND DESCRIPTION OF FELDSPAR

The lime rock containing the authigenic albite crystals is an extremely fine grained, massive, bedded formation of exceptional purity. For many years the rock has been used as a source of commercial lime, and, not infrequently, outcrops of this rock over central Pennsylvania mark the location of small operations of the lime industry. The present paper deals only with the authigenic feldspar from the Bellefonte exposure, but in the future it is hoped the rocks of other localities may be examined for feldspar content.

The thickness of the quarry rock at the location studied is about 100 feet, and since the beds are nearly vertical it was possible to sample the entire thickness. Twenty-five specimens were collected and upon examination of the residues, 17 were found to contain authigenic albite. In some instances the feldspar forms as much as 90 per cent of the insoluble residue, but usually it occurs in lesser amounts along with doubly terminated prismatic quartz crystals and such heavier accessories as tourmaline, zircon, and mica. The feldspars are therefore more or less uniformly distributed through the

[1] A preliminary study of the microscopic characteristics of the Black River formation was made by A. P. Honess and J. E. Doerr during the autumn of 1926.

rock and do not appear to be confined to special horizons. Beneath the microscope, the rock itself appears to be composed of extremely fine grained, semi-opaque areas of carbonate interspersed by irregular channels or veinlets of more coarsely crystallized calcite. The albite crystals observed in thin sections of the rock appear to be confined to the finer grained, semi-opaque material, although residues collected from white vein calcite near a fault zone showed authigenic feldspar in very small quantity which is identical to that of the wall rock. This is interpreted as coming from small fragments of the wall rock included in the larger calcite veins and is therefore not connected genetically with the meteoric vein calcite.

The albite crystals are distinctly euhedral, the best developed faces being (001) (010), (110), (1$\bar{1}$0), and small pyramidal planes. In size they approach one-fourth millimeter at a maximum along the major diameter and although many are smaller they are very uniform in habit and appear to be of approximately the same chemical composition throughout the entire thickness of the beds sampled. They are fresh in appearance and occasionally carry carbonate granules or rhombs as inclusions. Most of the larger crystals show the characteristic dual and lamellar twinning, but some reveal a more complicated type.

PREPARATION AND ANALYSIS OF MATERIAL

After a preliminary examination of the specimens collected, six were chosen as especially suitable for detailed microscopic and chemical analysis. The samples selected were prepared by crushing to $\frac{1}{4}$ inch in diameter, and the acid insoluble residues were obtained after solution of approximately 3 pounds in 1–3 hydrochloric acid. Solution of the limestone samples was carried out in three-liter beakers, completeness of solution being assured by digestion on a steam bath until all effervescence had ceased. Clay and organic matter were removed by repeated decantation, using a dilute solution of Na_2CO_3 as a deflocculating agent, until a residue of fine sands remained. The sands were then washed with water by means of the centrifuge until there was no test for chlorides, then with 95 per cent alcohol and finally with acetone. The acetone remaining after decantation was removed by drying in an oven at 65°C.

A heavy liquid was prepared which consisted of a mixture of symmetrical tetrabromethane and nitrobenzene in which albite would float and quartz sink. As a check on the constancy of the specific gravity of the mixture, quartz and albite crystals were kept as indicators in the mixture at all times when not in use.

The heavy liquid separations were carried out by means of the centrifuge, using a tube as illustrated in figure 2. The technique employed was that described by Volk (1933) which consists essentially of thoroughly evacuating the mixture of heavy liquid and sands to remove occluded air before centrifuging. This point is of extreme importance in all heavy liquid separations and contributes materially to the completeness of separation. After centrifuging, the feldspar fraction was poured onto a hard filter paper, a cork on a glass rod inserted into the tube as shown in figure 2, and the feldspar adhering to the side walls washed out by means of acetone. The excess heavy liquid was then removed from the feldspar by washing on the filter with acetone.

In most cases the feldspar fraction was contaminated with some organic matter, which was easily removed by further separation, using a heavy liquid in which the feldspar would sink and the organic matter float. This separation resulted in the feldspar being collected in the lower end of the tube where it was washed free of excess heavy liquid by means of acetone and dried at 65°C. Washing the excess heavy liquid out of the feldspar was facilitated by forcing a fine stream of

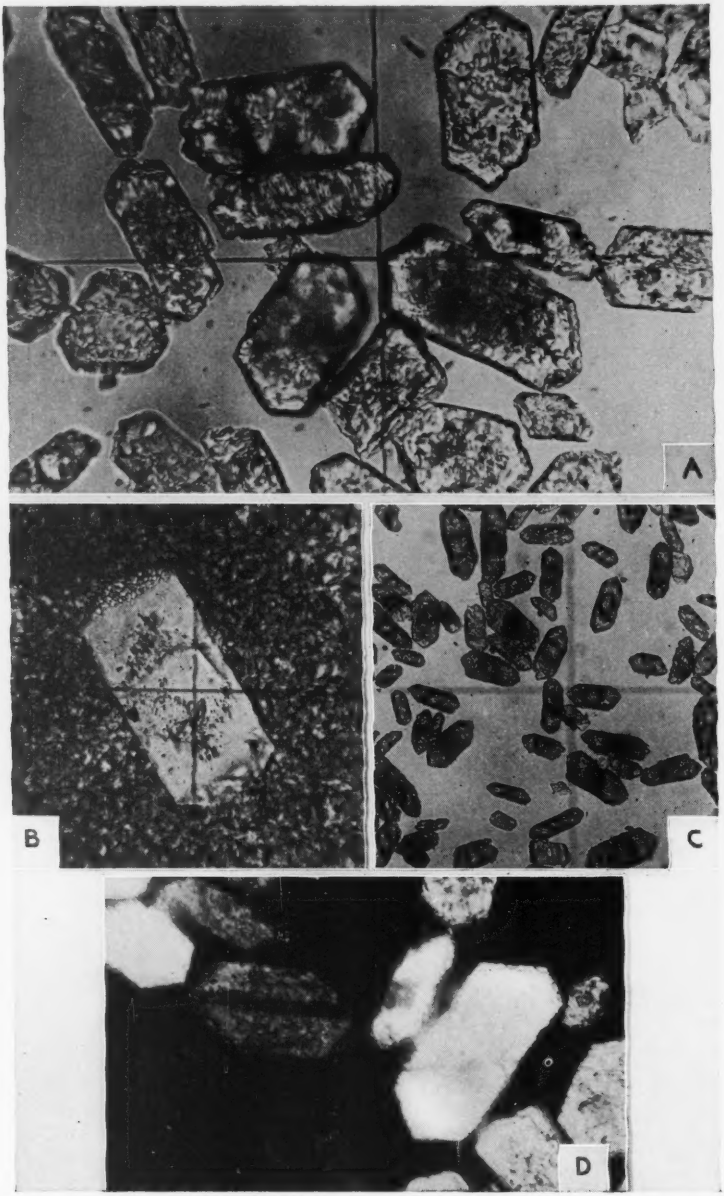

FIG. 1.—(See next page for legend.)

compressed air through the mixture of feldspar and acetone before centrifuging and decantation to remove the acetone wash.[2]

The feldspar fractions thus prepared, upon microscopic examination proved to be free from all contaminating substances and to be suitable for complete chemical analysis.

The feldspars obtained were analyzed, using standard methods of rock analysis according to Hillebrand and Lundell (1929). The sodium was determined by the uranyl zinc acetate method. Potassium was not detected in the albite crystals, but determinations were carried through using the sodium cobalti nitrite method described by Volk and Truog (1934), which is very accurate in the estimation of small quantities of potash. Extreme care was exercised as to purity of reagents in all cases.

The analyses are contained in table 1. These analyses show the uniformity of composition of the feldspar separated from the different samples. In calculating the composition, the loss on ignition was assumed to be CO_2, as in many cases small inclusions of carbonate had been observed in the feldspar crystals. Calcium was assumed to have been replaced by magnesium. The excess of calcium over that necessary to combine with CO_2 to form a carbonate was calculated as anorthite. The average composition of the feldspar calculated thus is albite 98.3 per cent, anorthite 1.7 per cent, which corresponds with the optical data.

Optical data.—Measurements of 2V were made by the universal stage. The values obtained varied between 70° and 75°, the average of 11 determinations on crystals from different horizons being 73°. The mineral is optically +. The indices of refraction determined by the oil immersion method, using white light, are α 1.528, β 1.531 and γ 1.538 ± .003. The extinction angles measured on the larger albite crystals are about 4° on the base, and about 17° on the side pinacoid.

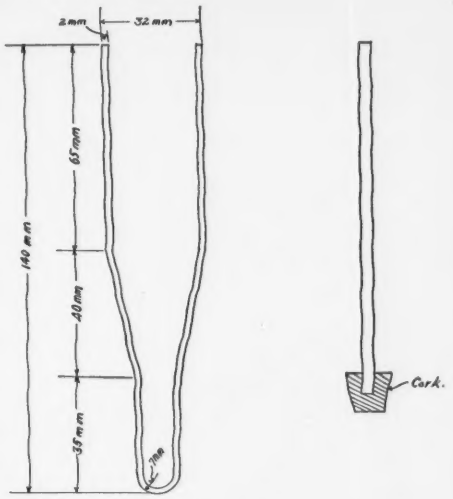

FIG. 2

Centrifuge tube of heavy pyrex glass. Plunger, to be inserted after pouring off light fraction before washing tube with acetone.

[2] Residues prepared in this manner are free of any filter paper fibres, and their weight may be accurately determined by weighing the centrifuge tube, first empty, and later with the residue.

FIG. 1.—Photomicrographs of authigenic crystals. a. Authigenic albite crystals from the Lowville limestone at Bellefonte, Pennsylvania, ×285. b. Authigenic albite crystal embedded in the Lowville quarry rock, Bellefont, Pennsylvania, ×285. c. Authigenic quartz crystals with numerous carbonate inclusions, from the Lowville limestone, Bellefonte, Pennsylvania, ×60. d. Twinned authigenic albite crystals from the Lowville beds, Bellefonte, Pennsylvania, Crossed nicols. ×285.

No attempt is made in this paper to discuss the literature on authigenic feldspars, since several more recent publications give adequate summaries. Boswell (1933) reviews the subject of authigenic feldspars and emphasizes the European occurrences. Daly (1917) appears to have been the first to report on feldspar of probable authigenic origin in North America. A few years later authigenic feldspars were reported from North Carolina (Laughlin, Berry and Cushman 1921). Singewald and Milton (1929) described authigenic albite from the Glens Falls limestone of New York. Goldich (1934) has described potassium feldspar overgrowths from the New Richmond sandstone of southeastern Minnesota, and Derry (1934) reports probable authigenic occurrences of both soda and potash feldspars from the Ordovician sediments of Ontario. Tester and Atwater (1934), in their description of the authigenic feldspars found in the sediments of Iowa, Minnesota, Kansas, New York, and Wisconsin, mention their importance as horizon markers. Atwater and Clement (1935) noted similar occurrences in Wisconsin and Minnesota. Thiel (1935) discovered feldspar overgrowths occurring at widely separated areas from various stratigraphic horizons within the St. Peter sandstone, and Tyler (1936) observed such feldspars in the same formation in Wisconsin. An occurrence of albiclase replacing fossils in a pure limestone of Mississippian age in Utah is mentioned by Stringham (1936). Gruner (1937) concluded that the fine feldspar matrix occurring in the clayey beds of the Glenwood formation near Minneapolis is a potash feldspar of authigenic character. Stewart (1937) described an occurrence of detrital authigenic feldspar which occurs as overgrowths in a lacustrine plain underlying the Flint moraine near Mt. Morris, Michigan.

Although these papers often give detailed description of the occurrence of the feldspars, discussions dealing with genesis are brief or wholly wanting. Therefore a further suggestion as to manner of formation may be desirable.

TABLE 1. *Chemical composition of authigenic albite from the Lowville limestone, Bellefonte, Pennsylvania*
Analysis by C. D. Jeffries

	1	2	3	4	5	6	Average
SiO_2	67.40	67.96	67.75	67.63	68.32	68.07	67.86
Al_2O_3	19.88	19.73	19.64	19.64	19.88	19.31	19.68
Fe_2O_3	0.11	0.05	0.18	—	0.21	0.33	0.15
CaO	0.32	0.37	0.78	0.87	0.46	0.50	0.55
MgO	0.15	0.16	0.20	0.19	0.16	tr	0.14
Na_2O	11.70	11.48	11.54	11.40	10.69	11.11	11.32
K_2O	—	—	—	—	—	—	—
Loss on Ignition	*0.27*	*0.29*	*0.30*	*0.26*	*0.30*	*0.41*	*0.31*
Total	99.83	100.04	100.39	99.99	100.02	99.73	100.01

EVIDENCE FOR AUTHIGENIC ORIGIN OF THE ALBITE CRYSTALS IN THE LOWVILLE LIMESTONE

Considered from the evidence at hand, the matter of genesis does not permit of any very direct solution. One may feel reasonably certain, however, that the albite crystals occurring in the Lowville limestone at Bellefonte, Pa., are of authigenic origin, since they are of uniform composition, habit and size, and are neither confined to special horizons, nor related genetically to any system of fracture zones which may be considered avenues of circulation for hydrothermal solutions. The enclosing rock shows no trace of metasomatic change or heat effects of

any kind, nor do the feldspar crystals appear to show replacement features in the rock such as those described by Black (Hatch, Rastall and Black 1938). Rather they suggest formation in the calcareous muds of the sea floor during deposition and compaction of the sediment. Since albite, formed by hydrothermal solutions, usually carries a determinable amount of potassium, it is also worth noting that six complete analyses of the feldspar taken from different parts of the formation reveal no trace of this constituent. The temperature element, therefore, appears to be practically eliminated in this particular occurrence, and whatever mechanism of genesis one may assume, it seems likely that time may have been an important factor. The suggestion of a clastic origin for the albite is unacceptable because of the definite idiomorphic habit, the manner of dissemination through the rock, the uniformity and special character of the chemical composition, and the dearth of the other usual depositional materials.

It is rather significant that the so-called authigenic feldspars which have been described are associated with calcareous rocks such as limestones, dolomites, chalk deposits, marl, and calcareous sandstones; also the variety of feldspar most usual in the purer limestones appears to be albite which is frequently accompanied by authigenic prismatic quartz, and more or less organic matter. Just how a solution of high lime concentration should favor the formation of nearly pure soda plagioclase is not understood. However, natrolite, analcite and other zeolitic minerals are recorded from sea-bottom deposits where their formation may have resulted from interaction of sea water and the alteration products of volcanic materials which are known to occur in present day aragonite muds (Hatch, Rastall and Black, 1938). In chemical composition these minerals are very similar to albite, but, being hydrated and possessing open, unstable structures, such compounds in the presence of silica might well suffer reorganization and transformation to albite during compaction of the sediment. Elevated temperatures are probably not necessary to convert zeolites to feldspars, and the suggestion seems pertinent that compressive forces during compaction of the muds at nearly normal temperatures, acting for considerable periods of time may influence the formation of albite. According to Clarke (1896) and Van Hise (1904), some of the zeolitic minerals are known to change to feldspars, alterations of this kind often being of simple nature involving exchange of alkalies or the substitution of alkalies for calcium at temperatures not far from normal. It may be mentioned, also, that the formation of albite at lower temperatures in a special environment of this kind may explain the absence of any determinable quantity of potassium which appears to be present nearly always in albite of hydrothermal origin. This is possibly due to sufficient expansion of the structure to permit a small amount of potassium to enter in solid solution. The fact that volcanic glass occurs so frequently in aragonite muds and that zeolitic minerals are so frequently associated with volcanic muds suggests an agency by which the feldspar may have formed. Whether the zeolitic stage is essential or whether these feldspars have been deposited directly from solution, as appears to have been the case in certain overgrowths, is not known. A systematic study of the residues of present calcareous muds may contribute something of value to this problem.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 10, NO. 1, PP. 19–32, FIGS. 1–4, TABLES 1–3, APRIL, 1940

SEDIMENTS OF BUZZARDS BAY, MASSACHUSETTS

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ABSTRACT

The modern sediments of the bay are described principally by the use of quantitative data derived from mechanical, mineralogical and chemical analyses. The environment of the sediment and its source and mode of deposition are discussed.

INTRODUCTION

This study is a part of the program of the Woods Hole Oceanographic Institution relating to the investigation of sediments of the Continental Shelf and coastal waters of the eastern United States. The field work and a part of the laboratory work were done under the auspices of the Oceanographic Institution during the summer of 1934. The remainder of the laboratory work was done subsequently in the sedimentation laboratory of the University of Chicago.

Buzzards Bay is a deep indentation of the shoreline which marks the western boundary of Cape Cod (fig. 1). The bay is 28 miles long, averages about 8 miles in width, and has an average depth of about 50 feet in its central portion. The surface area of the bay is 235 square miles, and the area of the land draining into it is 385 square miles, only 1.64 times as great. The relief of the land draining into Buzzards Bay is low, the maximum elevation in the watershed being between 200 and 300 feet. This land is gently rolling and poorly drained with numerous lakes and marshes. There is a good cover of vegetation and the soils are sandy and porous so that erosion takes place slowly.

The northwestern and northern shores are deeply indented whereas the eastern and southeastern shores are more regular. A chain of islands separated by tidal channels forms the southeastern side of the bay. The Cape Cod Ship Canal connects the head of Buzzards Bay with Cape Cod Bay to the northeast. The water in the bay has nearly the same concentration of salt as the adjacent ocean water, since tidal currents cause frequent interchange between the two bodies and there are no large streams bringing in fresh water.

The northwestern shore of Buzzards Bay represents, roughly, the edge of a shield of igneous rocks and Paleozoic sediments that constitutes the bulk of the New England Lowland. A few deep well borings show that the surface of the crystalline mass extends beneath Cape Cod to the east and south. The bed rock of the northwestern shore of Buzzards Bay is the Dedham granodiorite, upon which lies a shallow, discontinuous cover of glacial drift and recent sediment. Thick deposits of glacial drift form the other shores of the bay. A frontal moraine extends from the northeastern corner of the bay southward to Woods Hole (fig. 2), turns southwestward and forms the Elizabeth Islands that separate the bay from Vineyard Sound. It may be traced in shoals lying southwest of the islands for a distance of 12 miles. This moraine is the inner one of two prominent ridges of drift making up a large part of Cape Cod and the New England Islands.

GEOLOGIC HISTORY OF THE REGION

Nantucket, Martha's Vineyard, Block Island and Long Island mark the edge of an almost completely submerged cuesta of Tertiary and Cretaceous rocks which formerly extended farther northward and overlaid the older rocks of the mainland. The more or less continuous depression between this cuesta and the New England oldland probably was formed by subaerial erosion during a time of extreme lowering of sealevel in the late Tertiary (Veatch, 1906). Pleistocene glaciation modified the surface of the oldland to some small degree and formed the system of moraines and outwash plains which constitute the bulk of Cape Cod and the New England Islands. In late Pleistocene time, the sea was perhaps as much as 200 feet below its present level when the glacial ice disappeared from southern New England. The bottoms of Buzzards Bay and similar features must, therefore, have been exposed to subaerial processes for at least a short time.

TOPOGRAPHY OF THE BOTTOM

The bottom topography (fig. 2) when considered in detail is irregular and reflects the effects of glaciation. Submerged ridges parallel to the Elizabeth chain apparently are poorly developed recessional moraines. Certain details of topography, such as the deep channel leading seaward from the mouth of the bay and the extension of the 40-foot contour toward the head of the bay, may have resulted from the late glacial subaerial erosion.

The greater part of the bay is less than 50 feet deep, but a depression near Quicks Hole attains a depth of 126 feet and channels in the mouth of the bay contain depths of 100 to 140 feet. The

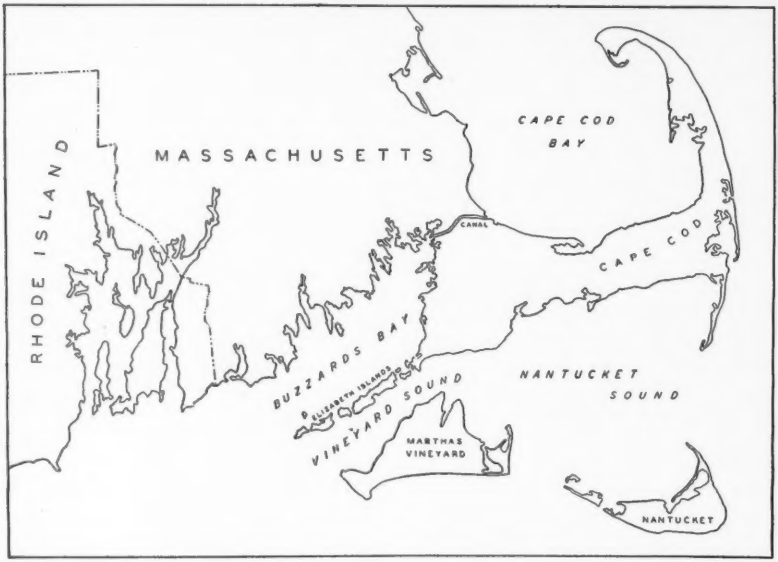

FIG. 1.—Index map showing location of Buzzards Bay.

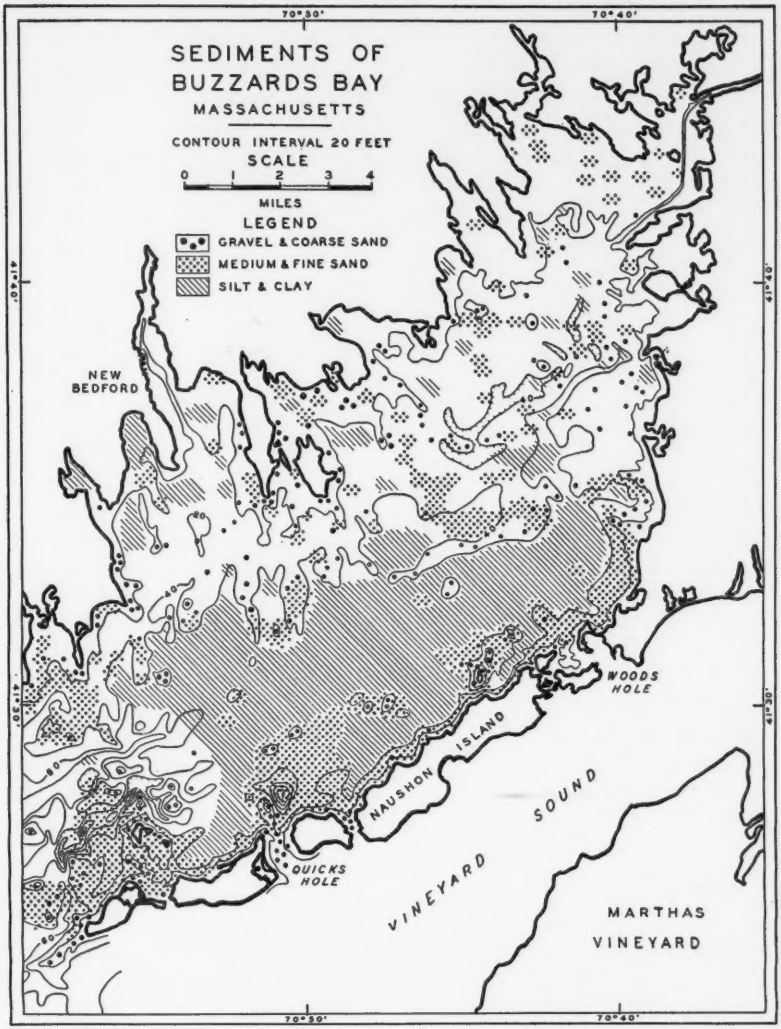

FIG. 2.—Sediments of Buzzards Bay. Shoreline and topography based on U. S. Coast & Geodetic Survey Chart No. 249, July, 1933.

low ridges forming the promontories of the northwest shore are roughly parallel to the direction of ice-movement during glaciation. At the head of the bay these ridges trend southeastward whereas at the mouth of the bay they trend nearly

southward. An orientation roughly normal to the line of the moraine on the opposite side of the bay is thus maintained. Shoals in the northwestern side of the bay mark the extensions of the ridges under water.

FIELD METHODS

Field work was done from the *Asterias*, a 40-foot power boat of fisherman type owned by the Oceanographic Institution. Bottom sampling apparatus consisted of coring tubes, a clamshell snapper and a Stetson-Iselin sampler (Hough 1939).

Two hundred and twenty-five samples were taken, most of them serially along lines crossing the bay at intervals from near its head to its mouth. In running these lines, departure was taken from some fixed point such as a buoy. The distance between stations was measured by taking the travel time of the boat which was operated at a constant speed between stations, and the lines were terminated at some other fixed point. In most of the series, the distance between samples was one-half mile. Coarse-grained sediments were stored in glass jars and cores of fine-grained sediments were wrapped in newspapers.

LABORATORY METHODS

The mechanical composition of the sediments was studied by the sieving (Wentworth, 1926) and the pipette (Krumbein, 1932) methods. The sieves used were graduated on the basis of the square root of 2. The weight percentages of material in the different size grades were calculated as cumulative percentages, and cumulative curves were drawn from which the first quartile (Q1), median (M) and third quartile (Q3) diameters were read. The statistical constants devised by Trask (1932) for sorting and skewness were then calculated for each sample. The sorting factor, So., equals $\sqrt{Q3/Q1}$ and the skewness, Sk., equals $Q1 \times Q3/M2$. In these equations Q3 is greater than Q1. The log of the skewness (to the base 10) is used in presenting the data. The results of the mechanical analyses are given in table 1.

In making a mineralogical study, small-sized separates of one size-grade common to several samples were obtained by use of a miniature sample-splitter of the Jones type (Otto, 1933). Separation into light and heavy fractions was then made with bromoform of specific gravity of 2.76. The fractions were mounted on microscope slides in piperine. This medium was used because its index of refraction falls near the center of the range of the indices of the heavy minerals. The minerals were identified by a petrographic microscope, and their frequencies were determined by counting the number of each species found in making three or four traverses on each slide. Between 100 and 300 grains were counted in each slide.

The acid-soluble material (assumed to be largely calcium carbonate) was determined by weighing the dried material, treating it with dilute hydrochloric acid (1:4), filtering, drying, and reweighing.

Data on the organic content of the sediments were supplied by H. R. Seiwell, chemist of the Woods Hole Oceanographic Institution, who made the determinations on samples which he collected for the purpose.

BOTTOM SEDIMENTS

The sediments of Buzzards Bay range from black, fine silts to clean, washed gravels and boulders. Cumulative curves of all the sediments analyzed were plotted on one graph. This showed a more or less regular gradation from fine-grained, rather poorly sorted sediments to coarse-grained, well sorted sediments. Since there is no distinct grouping of the samples into types, an arbitrary separation is made on the basis of the Wentworth classification. Gravel and coarse sand (median diameter greater than 0.500 mm.) are grouped together, sands of medium and fine grade (median diameter 0.500 to 0.061 mm.) are placed in a second group and silts and clays (median diameter less than 0.061 mm.) form a third. The distribution of these three groups in the bay is shown in figure 2.

TABLE 1. *Mechanical composition of sediments of Buzzards Bay, Massachusetts*

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
1	41°39′08″	70°45′07″	19	.170	.250	.360	1.456	−.010	
2	39′08″	44′47″	22	.142	.211	.310	1.478	−.004	
3	39′08″	44′07″	24	.185	.280	.490	1.628	+.064	
4	39′09″	43′28″	23	.260	.382	.560	1.470	.000	
5	39′10″	42′48″	19	.381	.586	.985	1.605	+.038	
6	39′11″	42′08″	25	.010	.047	.111	3.263	−.286	
7	39′12″	41′30″	42	.211	.413	.680	1.794	−.077	
8	39′12″	40′51″	30	.180	.302	.537	1.726	+.026	
9	39′09″	40′22″							Hard Bottom
10	38′47″	40′48″	29	.182	.381	.610	1.828	−.116	
11	38′24″	41′13″	33	.203	.428	.710	1.870	−.104	
12	37′54″	42′00″	42	.051	.366	.645	3.560	−.595	
13	37′58″	42′22″	18	.439	.579	.724	1.280	−.022	
14	38′08″	42′37″	26	.325	.510	.745	1.512	−.031	
15	38′50″	44′24″	28	.187	.286	.438	1.530	−.001	
16	38′20″	44′18″	30	.231	.337	.457	1.410	−.032	
17	37′49″	44′14″	29	.050	.302	.480	3.100	−.582	
18	37′18″	44′08″	36	.239	.321	.437	1.353	+.004	
19	36′22″	43′48″	31		>.500				*
20	35′55″	43′38″	38		<.061				*
21	35′27″	43′27″	39		>.061				*
22	35′00″	43′17″	38		>.061				*
23	34′32″	43′07″	39	.195	.267	.362	1.360	−.005	
24	34′05″	42′56″	33		>.061				*
25	33′52″	42′46″	41		>.061				*
26	33′22″	42′37″	46		<.061				*
27	32′53″	42′25″	46		<.061				*
28	32′24″	42′12″	42		<.061				*
29	31′55″	41′59″	34	.105	.241	.410	1.980	−.130	
30	35′30″	40′09″	28						Hard Bottom
31	35′17″	40′40″	39	.283	.482	.661	1.530	−.094	
32	34′43″	41′44″	45	.005	.014	.042	2.920	.000	
33	34′26″	42′18″	37		<.500				*
34	34′17″	43′33″	36		<.500				*
35	34′30″	44′09″	41		<.500				*
36	35′02″	40′10″	51	.006	.021	.051	2.890	−.135	
37	34′45″	40′11″	33		<.500				*
38	34′34″	39′51″	28	.354	.592	.968	1.654	−.010	
39	34′38″	39′32″	38	.350	.567	.910	1.612	−.004	
40	34′45″	39′11″	36	.325	.714	1.425	2.092	−.040	
41	34′07″	40′24″	41		<.500				*
42	41°33′08″	70°40′59″	46		<.061				
43	32′10″	41′34″	38		<.500				*
44	33′47″	42′23″	46		<.061				
45	33′28″	41′48″	49	.006	.018	.049	2.780	+.004	
46	33′11″	41′14″	47		>.061				*
47	32′54″	40′38″	37		>.061				*
48	32′44″	40′19″	33		>.061				*
49	32′36″	40′04″	30		>.061				*
50	36′44″	47′31″	23	.200	.255	.323	1.270	−.002	
51	36′15″	47′12″	29	.219	.300	.409	1.370	−.002	
52	35′52″	46′45″	37		.110	.246			*
53	35′28″	46′14″	37	.212	.326	.483	1.510	−.015	
54	35′05″	45′53″	37	.276	.426	.617	1.490	−.030	
55	34′42″	45′26″	39	.258	.404	.616	1.540	−.057	

* Determinations by partial analysis and inspection.

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
56	34′19″	45′00″	43	.230	.352	.556	1.550	+.013	
57	33′56″	44′34″	43	.202	.334	.530	1.620	−.020	
58	33′33″	44′08″	45	.005	.010	.020	2.078	−.020	
59	33′08″	43′42″	46	.004	.008	.017	2.130	−.012	
60	32′46″	43′16″	47		<.074				*
61	32′22″	42′50″	45		.181				*
62	31′58″	42′23″	35	.222	.433	.791	1.890	−.024	
63	31′41″	41′42″	35	.178	.245	.345	1.391	+.009	
64	31′28″	41′39″	24						Gravel
65	34′51″	48′36″	28	.121	.200	.300	1.580	−.043	
66	34′31″	48′10″	28	.240	.377	2.310	3.100	+.591	
67	34′10″	47′45″	36	.177	.305	.490	1.660	−.031	
68	33′06″	46′22″	44		<.074				*
69	32′44″	45′55″	46		<.074				*
70	32′22″	45′29″	46		<.074				*
71	32′00″	45′02″	47		<.074				*
72	31′38″	44′35″	48	.222	.295	.426	1.380	+.037	
73	33′49″	50′19″	34	.125	.177	.254	1.420	+.005	
74	33′25″	49′54″	48		.165	.262			
75	33′02″	49′29″	30	.515	.670	.985	1.380	+.053	
76	32′38″	49′02″	47	.007	.020	.049	2.690	−.087	
77	32′16″	48′37″	49	.005	.014	.035	2.626	−.056	
78	31′52″	48′12″	51	.005	.016	.037	2.615	−.107	
79	31′29″	47′47″	48	.008	.024	.053	2.624	−.163	
80	30′44″	46′53″	45	.006	.025	.055	2.940	−.253	
81	30′20″	46′28″	45		<.061				*
82	29′57″	46′03″	48	.007	.024	.050	2.630	−.200	
83	29′34″	45′36″	30	.015	.077	.240	4.050	−.226	
84	31′30″	47′18″	48		<.061				*
85	31′47″	46′46″	46	.007	.021	.042	2.440	−.180	
86	31′53″	46′12″	47		<.061				*
87	32′14″	44′24″	48		<.061				*
88	41°31′53″	70°54′27″	40						Gravel
89	31′53″	53′46″	32	.043	.228	.480	3.340	−.390	
90	31′52″	53′04″	46		<.061				*
91	31′52″	52′20″	47	.008	.029	.059	2.710	−.252	
92	31′52″	51′38″	37	.024	.115	.222	3.060	−.397	
93	31′51″	51′17″	47	.045	.158	.254	2.400	−.345	
94	31′55″	50′44″	47	.121	.176	.247	1.428	−.017	
95	32′02″	50′31″	25						One pebble
96	32′07″	50′19″	40	.167	.217	.307	1.355	+.037	
97	31′35″	50′07″	46		<.061				*
98	31′22″	49′30″	54		<.061				*
99	30′09″	48′53″	50		<.061				*
100	30′58″	48′04″	47		<.061				*
101	31′01″	47′31″	46		<.061				*
102	31′03″	46′53″	46		<.061				*
103	31′06″	46′17″	46	.005	.014	.037	2.690	−.020	
104	31′09″	45′40″	48	.050	.202	.370	2.720	−.343	
105	31′12″	45′05″	46	.178	.353	.579	1.800	−.080	
106	31′13″	44′47″	42	.215	.315	.468	1.480	+.006	
107	31′14″	44′29″	41	.223	.295	.407	1.350	+.018	
108	31′19″	43′57″	28	.187	.341	.550	1.710	−.051	
109	31′25″	43′17″	43		<.061				*
110	31′27″	42′57″	44		<.061				*
111	31′30″	42′37″	39		.062	.238			*
112	31′32″	42′17″	44	.155	.230	.308	1.410	−.045	
113	30′17″	45′40″	45		<.061				*
114	30′36″	45′06″	46	.005	.014	.038	2.700	+.004	

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
115	30′37″	47′54″	46	.016	.041	.070	2.060	−.188	
116	30′04″	47′19″	38	.012	.038	.066	2.320	−.250	
117	29′43″	46′56″	43	.009	.036	.060	2.580	−.370	
118	29′22″	46′34″	45	.008	.032	.055	2.720	−.377	
119	29′11″	46′23″	18	.172	.422	1.195	2.640	+.065	
120	31′00″	50′23″	56	.009	.030	.069	2.840	−.173	
121	30′52″	49′59″	56	.011	.039	.079	2.680	−.246	
122	30′36″	49′27″	52	.025	.080	.110	2.100	−.367	
123	30′18″	48′57″	51	.029	.089	.123	2.052	−.342	
124	30′00″	48′27″	48	.013	.051	.087	2.770	−.362	
125	29′42″	47′57″	44	.009	.035	.066	2.740	−.314	
126	29′24″	47′27″	46	.032	.147	.382	3.450	−.248	
127	29′05″	46′56″	42	.049	.135	.251	2.260	−.172	
128	30′33″	50′27″	56		<.061				*
129	30′07″	50′35″	56		<.061				*
130	29′41″	50′42″	54		<.061				*
131	29′15″	50′49″	51		>.061				*
132	28′49″	50′56″	51		>.061				*
133	41°28′23″	70°51′03″	63	.218	.320	.520	1.540	+.045	
134	27′59″	51′09″	80	.176	.256	.480	1.650	+.110	
135	27′57″	51′04″	100	.137	.431	.818	2.440	−.219	
136	28′10″	50′52″	79	.201	.287	1.370	2.610	+.526	
137	28′23″	50′40″	68	.164	.210	.318	1.390	+.072	
138	28′36″	50′28″	53	.114	.158	.189	1.290	−.063	
139	29′02″	50′05″	53		>.061				*
140	29′27″	49′39″	52		>.061				*
141	29′49″	49′15″	53		>.061				*
142	30′20″	48′51″	51						See Table 3
143	27′47″	51′08″	62	.198	.262	.350	1.330	+.005	
144	27′54″	50′48″	122	.182	.254	.520	1.690	+.165	
145	28′00″	50′29″	80	.152	.198	.265	1.319	+.012	
146	28′06″	50′10″	54	.100	.138	.180	1.340	−.025	
147	27′22″	48′40″	18						Gravel
148	27′36″	48′49″	25	.162	.200	.294	1.348	+.075	
149	27′51″	48′58″	39	.040	.078	.120	1.730	−.104	
150	28′19″	49′17″	39	.037	.080	.117	1.780	−.172	
151	27′35″	50′58″	66	.205	.725	4.116	1.418	+.207	
152	27′27″	50′40″	54	.148	.188	.250	1.300	+.019	
153	27′13″	50′51″	52	.165	.245	.427	1.608	+.069	
154	27′02″	50′55″	45						Gravel & shells
155	26′52″	50′52″	38						Gravel & algae
156	26′35″	50′52″	38						Gravel & shells
157	26′13″	50′40″	45						Gravel, shells & algae
158	26′03″	50′25″	40						Sand & shells
159	25′56″	50′05″	47						Sand & shells
160	31′00″	54′45″	60	.012	.044	.173	3.880	+.008	
161	30′50″	54′40″	30						Hard bottom
162	30′44″	54′40″	9						Hard bottom
163	30′36″	54′36″	20	.035	1.156	2.900	2.880	−.120	
164	30′29″	53′56″	52		<.061				*
165	30′22″	53′15″	52		<.061				*
166	30′13″	52′33″	57		<.061				*
167	30′00″	51′12″	56		<.061				*
168	30′24″	54′25″	39	.302	.575	1.045	1.860	−.020	
169	30′02″	54′02″	53		<.061	.068			*
170	29′40″	53′40″	63		<.061	.098			*
171	28′56″	52′56″	58		<.061	.102			*
172	28′34″	52′34″	57		<.061	.070			*

Sample No.	Latitude	Longitude	Depth in feet	Statistical constants Diameters in mm. Q1	Med.	Q3	So.	Log Sk.	Remarks
173	28'11"	52'11"	55		<.061	.084			*
174	27'44"	51'45"	28	.187	.287	.417	1.494	−.051	
175	27'36"	51'34"	33	.109	.144	.177	1.272	−.031	
176	27'30"	51'52"	61		<.061				*
177	27'18"	52'27"	48		<.061				*
178	27'05"	53'03"	44		<.061				*
179	26'53"	53'39"	39		<.061				*
180	26'26"	54'15"	20	.277	.467	.890	1.190	+.054	
181	26'20"	55'40"	18						Pebbles, sand & shells
182	30'35"	55'14"	40	.035	.200	.455	3.600	−.400	
183	30'05"	55'12"	53	.016	.034	.095	2.420	+.111	
184	31'25"	55'30"	38	.092	.332	.620	2.600	−.287	
185	31'05"	55'48"	48	.154	.282	.426	1.660	−.081	
186	30'41"	56'08"	50	.033	.148	.328	3.180	−.311	
187	30'16"	56'29"	38	.131	.253	.485	1.920	−.004	
188	29'52"	56'51"	36	.339	.462	.602	1.330	−.020	
189	29'13"	57'22"	28						(1st trial) 1 pebble
190	29'13"	57'22"	30	.190	.310	2.800	3.830	+.771	(2nd trial)
191	28'39"	57'12"	84	.010	.040	.121	3.405	−.112	
192	28'11"	57'02"	101	.026	.102	.281	3.260	−.146	
193	27'44"	56'52"	57	.311	.451	.628	1.421	−.011	
194	27'30"	56'47"	83	.172	.305	.526	1.750	−.011	
195	27'15"	56'42"	82	.297	.490	.922	1.765	−.058	
196	26'47"	56'32"	50	.185	.320	.605	1.805	+.095	
197	26'19"	56'22"	45	.130	.220	.414	1.780	+.045	
198	27'02"	57'10"	145	.145	.262	.371	1.600	−.104	

It may be seen that the coarser sediments generally occur in exposed areas near shore and on topographic highs. The finer sediments occur in the deeper south-central portion of the bay and in the protected embayments of the northwest shore. The deep holes in the mouth of the bay and the depression near Quicks Hole contain coarse sediment and, therefore, present a special problem.

The relation between median diameter of the sediment and depth of water was investigated by plotting these two figures for each sample on a graph. No significant degree of correlation was found. Differences in the degree of exposure to wave and current action on the irregular bottom are believed to be of greater importance than absolute depth in determining the characteristics of the sediments.

The sorting factor was plotted against median diameter in a graph (fig. 3), which indicates clearly the tendency for the finer sediments to be poorly sorted and the coarser sediments to be well sorted.[1] This graph shows a concentration of points between the sorting values 2.5 and 3.0, below a median diameter value of 0.061 mm. Another group of points is located between the sorting values 1.35 and 2.00 above the median diameter value 0.130 mm. There are no sediments with a median diameter less than 0.061 mm. having sorting factors less than 2.00, and comparatively few of

[1] On the basis of 170 samples of marine sediments, Trask set up the following classification of sorting: well sorted sediments are those with So. less than 2.5, normally sorted sediments are those with So. between 2.5 and 4.5, and poorly sorted sediments are those with So. greater than 4.5. (Trask, 1932, p. 72) Stetson gives an average of 1.45 for well-sorted, near-shore marine sediments. (Stetson, 1937)

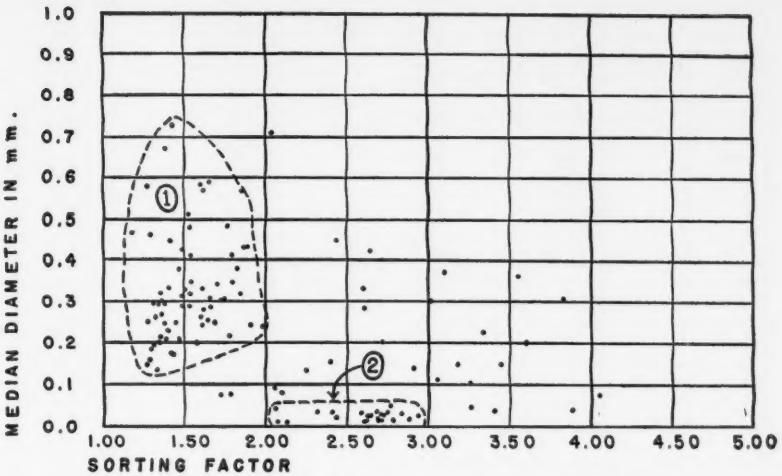

FIG. 3.—Graph of median diameter plotted against sorting factor.

the coarser sediments have sorting factors greater than 2.00.

The log of skewness was plotted against median diameter in another graph (fig. 4). This shows a group of points between the median diameter values 0.130 and 0.600 mm. having logs of skewness not exceeding plus or minus

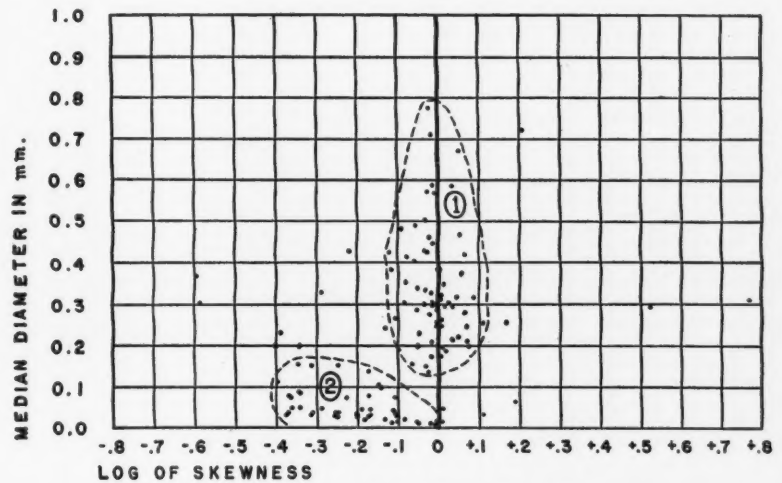

FIG. 4.—Graph of median diameter plotted against logarithm of skewness.

0.12, and being about equally distributed on either side of skewness log zero. A few of the coarser sediments are widely scattered on the graph. These are the same samples which have sorting values greater than 2.00 in figure 3. Practically all of the remaining samples fall into a group with median diameters less than 0.160 mm. and logs of skewness from zero to minus 0.40.

The deep hole in the bay north of Quicks Hole channel (fig. 2) contains sand having a median diameter of 0.254 mm. in its deepest part where the depth is 126 feet. No sediment finer than about 0.200 mm. median diameter was found in the depression, but in many places outside this area, in less than 60 feet of water, sediment of less than 0.061 mm. median diameter was found. Quicks Hole channel is floored with an erosion resisting pavement of coarse gravel and organic growth (mainly calcareous algae and hydrozoa) while the shoal extending northward from the west side of Quicks Hole to Lone Rock is composed of gravel and coarse sand with a large amount of shell material. Between Lone Rock shoal and the bottom of the 126-foot depression the sediment decreases in grain size but maintains its clean-washed, oxidized appearance and its high shell content. The strong tidal currents of Quicks Hole pouring into Buzzards Bay seem to be directly related to this distribution of sediment. It is not possible to assign the origin of the depression to scouring by the tidal current, but the current apparently is responsible for the non-accumulation of fine-grained sediment.

Some of the closed depressions in the submerged channels in the mouth of Buzzards Bay also contain coarse sediment. Sand with a median diameter of 0.262 mm. is present at a depth of 140 feet in one of these holes. The reason for this occurrence is less clear than in the depression adjacent to Quicks Hole. However, it seems probable that the islands and numerous gravel covered shoals in the mouth of the bay produce a concentration of tidal flow sufficient to cause appreciable current velocity at the bottoms of some of the depressions.

MINERALOGICAL COMPOSITION

Nine samples were selected for mineralogical study. Six of these[2] were taken along a line crossing the bay at a right angle to its axis between Wilkes Ledge[3] and Quicks Hole. The remaining three samples[4] were taken on the sides of the deep hole north of Quicks Hole. The grade between 0.104 and 0.208 mm. was studied because all nine samples contained material in this range. No far-reaching conclusions can be drawn from the study of a single arbitrarily chosen grade, but the data indicate which minerals are present and permit certain generalizations to be made.

Quartz is the most abundant mineral in all of the samples. Orthoclase and plagioclase feldspars are second in abundance in most of the samples. The light fractions contain, besides the minerals just mentioned, a few Foraminifera, Ostracoda and fragments of Hydrozoa.

The heavy minerals identified in the samples are listed in table 2 with figures showing relative abundance. The most abundant heavy minerals are aragonite, opaque metallics, hornblende and muscovite. Brown tourmaline is present in small amounts in all the samples studied. The aragonite is organic in origin and represents fragments of animal tests. Biotite evidently is undergoing alteration from an original state in which its color is brown to a product which possesses a green color and is nearly isotropic in character. A few grains were observed which were partly brown and unaltered and partly green and nearly isotropic. Rare grains with a green color showing compound polarization were identified as glauconite, and, in the light of Galliher's work (1935), are believed to repre-

[2] Sample Nos. 163, 168, 170, 171, 173 and 175.

[3] Position, 41° 30′ 45″ N., 70° 54′ 40″ W., shown in figure 2 as a gravel covered shoal.

[4] Sample Nos. 143, 145 and 153.

sent the end product of alteration of the biotite. The opaque metallic minerals are largely magnetite, but include a small percentage of ilmenite and opaque brown constituents. The garnets are mainly salmon-colored, but a few colorless (blu-

inverse power function of the median diameter of the sample. These minerals make up only 3.8 per cent of the heavy fraction of the 0.104–0.208 mm. grade in a sample having a median diameter of 0.575 mm., whereas they constitute 84.9

TABLE 2. *Mineralogical composition of heavy fraction of 0.104–0.208 mm. grade, in nine samples of sediment from Buzzards Bay, Massachusetts**

Mineral	Sample number								
	163	168	170	171	173	175	143	145	153
	%	%	%	%	%	%	%	%	%
Aragonite	54.4	7.2	1.5	1.5	3.8	9.2	10.3	.9	11.9
Biotite (brown)	.8	—	4.4	5.1	3.8	4.5	1.0	6.7	—
(green)	1.6	4.1	14.8	20.1	16.8	5.3	3.4	1.7	2.8
Calcite	—	—	—	—	—	3.8	1.5	—	6.3
Chlorite	3.6	1.1	1.5	.7	.8	9.2	1.5	2.5	2.8
Enstatite	—	2.0	.7	—	.7	—	1.5	3.4	—
Epidote	3.2	—	7.4	.7	1.5	3.8	9.3	8.4	6.6
Ferrous metallics	13.9	44.4	4.4	.7	.8	6.9	17.1	25.1	27.9
Garnet	2.4	7.2	.7	—	—	.8	2.5	3.4	4.9
Glauconite	—	—	—	—	—	2.3	2.5	—	—
Hornblende	6.7	17.5	5.9	1.5	2.3	16.0	4.4	11.8	5.6
Kyanite	—	1.1	.7	—	—	—	—	—	.7
Muscovite	6.4	4.1	40.6	57.3	53.4	5.3	6.9	5.9	5.9
Olivine	—	—	—	—	—	—	1.0	—	—
Sillimanite	.4	—	—	—	.7	5.3	3.4	.9	2.4
Titanite	.4	1.0	—	.7	.8	—	1.5	1.7	.4
Topaz	1.6	—	—	—	—	.8	.5	—	1.0
Tourmaline	1.2	1.0	2.2	.7	.8	2.3	4.4	5.0	3.5
Zircon	.8	3.0	—	.7	—	—	—	2.5	1.4
Zoisite	—	—	—	—	—	—	.5	—	.4
Altered	2.0	5.1	9.5	2.3	9.2	12.2	11.2	4.1	7.7
Miscellaneous	.8	1.1	5.9	8.1	4.6	12.2	15.6	16.0	7.7
Heavy minerals in grade; % by weight	14.0	16.7	1.9	3.5	5.8	1.7	3.1	3.5	3.4
Depth of water in feet	20	39	63	58	56	33	62	80	52
Median diameter in mm.	1.156	.575	.061	.061	.061	.144	.262	.198	.245

* Refer to table 1 for location.

ish-colored in piperine) grains of the mineral occur. The zircons are bluish-purple in color, and most of them are well-defined crystals. Altered minerals include various light-colored opaque or translucent grains.

The amount of micaceous minerals, muscovite, biotite and altered biotite, present in the heavy fractions of the one size-grade studied, varies roughly as an

per cent of the corresponding part of a sample having a median diameter of 0.050 mm. The great abundance of the micaceous minerals in the coarser fractions of the fine-grained, mid-bay sediments can be explained on the basis of their low hydraulic values (or small equivalent diameters) relative to those of the more spherical grains occurring in the same sediment.

Localities favorable to the growth of shell-secreting organisms have bottom sediments containing much shell material. When shells occur in a situation where wave action is of importance, they are broken and much of the carbonate material is incorporated as sedimentary grains and finds a place in the regular size distribution of the sands. In the deeper waters of the bay where fine-grained sediment is accumulating, the shells are not mechanically broken and they occur as erratic particles of relatively large size and do not form a part of the regular size-distribution curves.

TABLE 3. *Acid-soluble material in sample no. 142,* Buzzards Bay, Massachusetts*

Depth in core	Acid-soluble material
Cm.	*Per cent*
0– 5	3.24
5–10	3.13
10–15	2.92
15–20	2.37
20–25	2.32

* Refer to table 1 for location.

In order to determine the variation in amount of acid-soluble material with depth in the sediment, a core sample (no. 142) of the fine-grained deposit in the south-central part of the bay was divided into sections of 5 cm. each, and a representative part of each section was treated with acid. Table 3 gives the results of this study. There is a small but continuous decrease in amount of acid-soluble material from top to bottom of the core. Stratification of this deposit is indicated partly by variation in quantity of shells. The recognizable layers have an average thickness of about 1.5 cm., but, as described below, these layers may include one or several years' contribution of sediment. Thus the 5 cm. sections may represent the accumulations of several years. The decrease in amount of carbonate with depth in the core must be due either to a long time trend in amount of carbonate deposited or to a slow solution of the carbonate. The shells in the deeper layers of several core samples examined are thin, lacking in lustre, and are structurally weakened thus showing the effects of solution.

ORGANIC CONTENT

The organic content of the fine-grained sediments of the bay averages about 2 per cent, as determined in analyses of 20 samples by Seiwell. The fine-grained material with this organic content possesses a black color when wet and a dark grey color when dry. In order to determine whether such a deposit might be a source sediment of petroleum, a calculation was made of the probable oil yield of the deposit.

Using Trask's data on oil yield of organic sediments (1932, p. 40), it may be calculated that one cubic foot of the fine-grained Buzzards Bay sediment could yield 0.07 cubic foot of oil. The area covered by the fine-grained sediment is roughly 100 square miles. A layer of sediment 10 feet thick in this area would have a volume of 28 billion cubic feet. At the rate of 0.07 cubic foot of oil per cubic foot of sediment, this deposit would produce 1,960,000,000 cubic feet or 350 million barrels of oil. It is thus seen that the fine-grained sediment of Buzzards Bay might be a source sediment of petroleum at some time in the future.

STRATIFICATION

Distinct stratification shown by variations in grain size or in shell content was observed in many of the core samples of fine-grained sediment. Freshly collected cores were laid horizontally on a table and sliced longitudinally by pushing a knife through them in a direction normal to the length of the core. Thin layers of fine sand were detected by prodding the exposed faces with a needle. Shells were located by carefully separating one of the halves of each core with a needle.

The layers observed were approximately 1 to 2 cm. thick. It is impossible

to say whether these layers represent annual deposits of sediment. An estimate can be made of the maximum thickness annual layers could have in the bay, as follows: the probable maximum depth that the bay could have had in any considerable area in its south-central part is 100 feet, a figure obtained by comparison of the topography of the bay with that of the adjacent Vineyard Sound and ocean floor. If the original depth were 100 feet, and the average present depth in the area of fine-grained sediment is taken as 50 feet, then a deposit of sediment 50 feet thick has been laid down. The minimum length of time during which water surface has been at or near its present level is taken as 10,000 years, the approximate period elapsed since withdrawal of the glacial ice from the area. Assuming that 50 feet of sediment were laid down in 10,000 years, the average thickness of one year's deposit is 1.5 mm. If compaction is taken into account, the surface layers of the deposit would have a thickness somewhat greater than this. Considering the grain size of the deposit, it is estimated that the porosity in its lower part would be about 35 per cent and the porosity in the upper 25 cm. would be about 65 per cent. The layers in the upper 25 cm. would have a thickness of about 2.3 mm.

The average thickness of the layers observed in the core samples is 1.5 cm., about 6.5 times as great as the calculated maximum possible thickness of annual layers. The discrepancy may be explained in two ways. (1) The thickness of observed layers may represent more than one year's deposit. This is possible if the coarser grains and the concentrates of shells observed in the cores represent unusual conditions occurring only once in several years. (2) The rate of accumulation of sediment may be greater at present than during most of the life of the bay. This is possible because the rate of erosion of the watershed probably has been increased materially by cutting of forests and cultivation of the soil.

INTERPRETATIONS

Sources of sedimentary material.—Because of its abundance and unconsolidated character, glacial drift is by far the most important source of sedimentary material. The constituents of the drift were derived from the land to the northwest, as shown by the fact that Dedham granodiorite is the most common type of rock present. In texture the drift is coarse; grains in the sand sizes are most abundant and little silt or clay is present. The Dedham granodiorite of the northwestern shore is comparatively very resistant to erosion; therefore, the amount of material it contributes directly is small. The mineralogy of the bay sediments is related to that of the granodiorite and indicates an ultimate origin in that rock mass.

A considerable amount of calcium carbonate is contributed to the sediments of the bay by shell-secreting organisms. Whole shells and shell fragments occur in abundance at the surface of the deposits, but solution of the carbonates apparently is taking place in the deposit so that they do not represent a permanent contribution of great importance.

Wave action.—The storm waves and swells of the open ocean reach only a short distance into the bay, because of the protection afforded by the islands and shoals at its mouth, but waves generated within the bay attain a considerable size. The more exposed shores of the bay show abundant evidence of wave attack in their low cliffs and boulder-strewn beaches. It is difficult to judge the intensity of wave action on the bottom of the bay. Coarse sediment occurs on topographic highs in as much as 40 feet of water. This coarse concentrate may have developed largely during a time of lowered sea level and since that time have been kept free of fine sediment and organic matter by gentle bottom currents. However, wave action at a depth of 40 feet in a body of water the size of Buzzards Bay should be capable of producing

the concentrate observed, since Kindle (1925) reports the destruction by wave action of a staunch vessel and the removal of its 75 tons of coal while sunk in 65 feet of water in Lake Ontario.

Tidal currents.—In the channels between the islands of the Elizabeth chain, the tidal currents have maximum velocities of 4 to 6 knots at the surface, and currents near the bottom in the center of the bay have maximum velocities of 0.5 knot.[5] Coarse sediment is transported in the tidal channels between the islands, but only fine silt and organic matter are carried into the central part of the bay.

Ice rafting.—During the colder winters a large amount of ice forms in the bay and in the adjacent sound. It is swept through the tidal channels and ground against the shores by the tidal currents. Some sedimentary material may be transported by the ice and rare particles of coarse sand and gravel occurring in the fine-grained sediments may have been contributed in this manner.

Change in topography of the bay.—The bay shores, subject to the most violent erosive action, have undergone little change in shape. Headlands and island shores have been cut back several feet. Many indentations have been reduced in curvature and some have been nearly closed off by deposition of sand and gravel, but the net change in configuration of the shore lines has been small. The presence of abundant boulders in the glacial drift results in the formation of a boulder pavement on the beaches that is very resistant to erosion.

The bottom topography has been rendered more gentle by erosion of the shoals and deposition in most of the hollows, but the shoal areas, like the beaches, are protected by coarse concentrates and, therefore, waste slowly. The greatest change in topography seems to have taken place in the central part of the bay where accumulation of fine-grained sediment has produced a gently sloping floor.

[5] Current velocities determined by the U. S. Coast and Geodetic Survey. The data were taken from unpublished records obtained from the Survey through the courtesy of R. S. Patton, director.

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SEDIMENTARY STUDIES OF THE WAPSIPINICON FORMATION IN IOWA

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ABSTRACT

Detailed field study, including the collection of samples, was made of the Wapsipinicon formation and adjacent Silurian and Devonian beds in Iowa. The Wapsipinicon consists of about 100 feet of limestones, dolomites, and calcareous shales that are divided from the base upward into the Coggan, Otis, Kenwood, Spring Grove, and Davenport members. In the laboratory, the samples were digested in acid to determine the amount of insoluble residue, the mineralogy of the residue was studied with the aid of a petrographic microscope, and the ratio of calcite to dolomite in the samples was determined by means of stains. All three criteria (percentage of insoluble residue, mineralogy of insoluble residue, and calcite-dolomite ratio) were found to be of aid in correlation, but they are rarely conclusive evidence except when used together and in conjunction with field evidence.

INTRODUCTION

The Wapsipinicon formation of the Devonian of Iowa was investigated in order to establish criteria by which the various members of that formation and adjacent formations could be distinguished. Numerous sections were described and samples collected for laboratory study. This study consisted in determining calcite-dolomite ratios and in determining the amount and mineralogy of the insoluble residues. The Wapsipinicon is adapted to this type of work because it is composed of fairly diverse calcareous rocks and, as it is practically unfossiliferous, paleontological methods can not be used to advantage. It outcrops in a narrow band from Fayette and Bremer counties on the north to Scott County on the southeast. Brief attention is also given to the Gower and Hopkinton dolomites of the Silurian.

The writer is indebted to Professors A. C. Tester and A. C. Trowbridge of the University of Iowa under whose guidance this work was done.

CALCITE-DOLOMITE RATIOS

The fact that certain strata are persistently either limestone or dolomite over wide areas has long been known and used as a correlative criterion in a general way. However, few detailed determinations of the ratio of calcite to dolomite in a complex series of calcareous beds have been made in an attempt to correlate them. The writer has attempted to do this, and staining was used to differentiate calcite and dolomite. Lemberg's and Heeger's solutions were recommended by Briard (1932) and the writer found them to be most satisfactory.

Lemberg's (logwood) solution was prepared by boiling together 0.24 gram haematoxylin (extract of logwood), 1.6 gram aluminum chloride ($AlCl_3$), and 24.0 cubic centimeters of distilled water. When applied to limestone, the reaction forms $AlOH_3$ on the calcite. This acts as a mordant and absorbs the logwood stain, giving the calcite a deep violet color.

Heeger's solution was made by mixing 0.2 gram concentrated hydrochloric acid, 1.0 gram of a saturated solution of potassium ferricyanide ($K_3Fe(CN)_6$), and 20.0 cubic centimeters of distilled water. When applied to dolomite, the reaction is the formation of ferrous chloride ($FeCl_2$)

TABLE 1. *Showing the distribution of limestone and dolomite in the Wapsipinicon and adjacent formations. Each dot represents one sample.*

Geologic Division	County	Dolomite 100–90 %	Dolomite 89–50 %	Calcite 50–89 %	Calcite 90–100 %
Cedar Valley	Scott				•••
	Linn				•
	Benton				•
	Fayette			•	•
Davenport	Scott				••••
	Linn				••
	Benton			•	
	Buchanan				•
	Fayette			•	•
Spring Grove	Linn	•	•	•	•
	Benton	•	•		
	Fayette	•••			••
Kenwood	Linn				•••
Otis	Scott				•
	Cedar	•••		•	•
	Linn	•••••••	•	•	••••
Coggan	Cedar	•••••••••			
	Linn	•••••••			
(Bertram)	Linn	••			
Gower and Hopkinton	Clinton	•			
	Cedar	••••••			
	Linn	••			
	Jones	••••			
	Fayette	•			
	Bremer	•			

from the ferrous carbonate ($FeCO_3$) present in the dolomite. The ferrous chloride then reacts with the potassium ferricyanide to form a deep blue-green precipitate of ferricyanide.

The sample is broken and sieved to the $\frac{1}{4}$–$\frac{1}{8}$ millimeter size and placed on a small watch glass. Two or three drops of the solution are placed on the grains and allowed to stand for five to eight minutes and then washed off. The stained and unstained grains are counted for percentage determination.

Lemberg's solution never fails to stain calcite, but it occasionally stains dolomite, especially if the dolomite is porous. Heeger's solution sometimes fails to stain dolomite due to lack of ferrous iron in the dolomite, and sometimes stains calcite, especially if too much argillaceous material is present. By using both solutions and checking the results against each other, it is believed that accurate results were obtained. The results are summarized in table 1. They show that calcite-dolomite ratios do have a definite correlative value and are a valuable adjunct to other types of information.

INSOLUBLE RESIDUES

The value of insoluble residues in the critical study of calcareous strata has already been demonstrated and the literature and technique need not be reviewed. Hydrochloric acid was used in this study rather than acetic acid because it is much more rapid in its action and is less expensive.

The percentage of insoluble residue

TABLE 2. *Showing the distribution of percentages of insoluble residues in the Wapsipinicon and adjacent formations. Each dot represents one sample.*

Geologic Division	% insoluble / County	0.05 to 0.49	0.50 to 0.99	1.00 to 1.99	2.00 to 4.99	5.00 to 9.99	10.0 to 24.9	25.0 to 100
Cedar Valley	Scott				•	•	•	
	Linn				•			
	Benton				•	•		
	Fayette					•		
Davenport	Scott	••	•	•	•			
	Linn			•	•			
	Benton				•			
	Buchanan	•						
	Fayette	•			•			
Spring Grove	Linn	•		•		•	•	
	Benton		•	•				
	Fayette	•	•	•		•		
Kenwood	Linn				•		•	••
Otis	Scott		•					
	Cedar	•••••		•	•			
	Linn	•••••	••	••	••	•	•	
Coggan	Cedar	••••	••	•	••	•	•	
	Linn	•••••	•			•		
Bertram	Linn	•		•	•			
Gower	Clinton	•						
	Cedar	•••••	•	•				
	Jones	•	••		•			
	Linn	•	•					
Hopkinton	Clinton, Linn, Jones, Fayette	•	•	•	•	••		

TABLE 3. *Showing the distribution of minerals in mutual percentages (in amounts of one per cent or more) in the insoluble residues of the Wapsipinicon and adjacent formations. The location of each section is shown in figure 2.*

Division	County	Section No.	Quartz detrital	Quartz secondary	Feldspar	Gypsum	Asphaltum	Hematite	Pyrite	Chert	Clay
Cedar Valley	Scott	3	1		5	3			3		87
		3	7	8					5	20	60
		3	1						25		74
	Linn	21				35		1			64
	Benton	23	6			1			30	1	55
		23				3					97
	Fayette	25			15						85
Wapsipinicon	Benton	23	5			2			12		81
		23	1						1		98
	Fayette	25	7	3	13	10				2	65
		26	25	5	1	15			1	3	50
Davenport	Scott	2	2	95							3
		2		90							10
		2		98							2
		2	1	95			3				1
		3		11					1	5	83
		3		85					15		
		3	60	5					20	5	10
	Linn	15	48	23		15		1		7	6
		21	20	4	1			15		2	58
		21	3	10		1		5		2	79
	Benton	23	25		6	2		2	5		60
	Buchanan	24	3			65		25			7
		24	2			50		47			1
		25		2		80	2				16
	Fayette	27	5			20					75
		27	4		15	21	50	3		2	5
Spring Grove	Linn	14	70	2	2	8				3	15
		14	12		4					1	83
		15	1	1		95			1		2
		15		14		4					82
		21	45	3	2					5	45
		21	3					40			57
	Benton	23	10		2				2	2	84
		23	18		1			50		1	30
		25		85					10		5
		25	5	30	20			2		4	39
		25	12		18						70
	Fayette	26	29	5	1				64	1	
		26	5	5		85	2		3		
		26			12	40		3		3	40
		27	8	2			3				87
		27	3	5		30	5	2			55
Kenwood	Linn	15	3		15				2		80
		20	5					1			94
		20	7					3			90
		20	1					20	5		74
		20		85				3		7	5
Otis	Scott	1	35	2			5			2	56
		1	2	1	3		1				93
	Cedar	4	1				1				38
		4	5								65
		4	10				1				79
		4	35				1				64
		5	3				2				90
		5	25		5					2	58
		6	5	47						3	47
		8	22	3	1						74
		8		5			1				90
		9		15	5						78
	Linn	13	15							1	44
		13	2								95
		14	5						1		94
		14	10						3		87
		14		87						3	10
		14		92						2	6
		14	10		10				45	5	30
		15	30						8		62
		16	33	2				1			64
		16	3				1	2			94
		16	5			3	15		5		72

Division	County	Section No.	Quartz detrital	Quartz secondary	Feldspar	Gypsum	Asphaltum	Hematite	Pyrite	Chert	Clay
Otis	Linn	16		55	14			10	1		20
		16		5				5			90
		18		15	5	5					75
		17	25	5	8		2				60
		17	2					5			93
		17		80				12			8
		17	2					42		1	55
		17	2								98
		18	30		10		3				57
		18	10		20						70
		19	3		2						95
		19				10		35	2		53
		19		5	25						70
		22		13	6		35	25	16	2	3
		22		55	10	3		5			27
Cooper	Cedar	4						2			98
		4	8								92
		4	12							3	85
		5	15					2			83
		5	12			5		3			80
		6	25					1			74
		6	5					3			92
		6		3				1			96
		6						10			90
		6	8								92
		6	4					1			95
		7	5								95
		7	1					12			87
		7	2					8			90
		7	5				1	35			59
		8		10							90
		8	4	2				4			90
		13	2	2							96
	Linn	13	2			1				80	16
		13	25					25			50
		13	22	3	2			30			43
		16						5			95
		17				30					70
		18	1			1	4				94
		18				8					92
		19	40		3		2			8	47
		19	4			15				1	80
		19	13	3			10			1	73
		19	55	5	3					2	35
		22	2	1	10	15	65	2		2	2
		22	20		7	3	30	25		15	
	(Central)	10	3					5			92
	Linn	10	15			35		45			5
		10	1		1			10			88
		11	5	5		35		3			52
		11	25			65		5			5
Gower	Cedar	4		70	28			2			
		4	8		2						90
		5			80			8	2		
		5		99				1			
		6	1		2			5			92
		6						12			88
		7	3		2			20			75
		7	2		8			40			50
		7	3		15			1			81
		7	2		40			50			8
	Linn	9	55		15			2			28
		9	15		1			3			80
		9	65					5			35
		9	25		2			3			70
		12	3	2							95
		12	25	3	40			2		20	10
		12	10	77	10					1	2
Hampton	Linn	18	27		50					3	20
		26	6		43					8	43
	Fayette	26	8		5				5	55	27
		26	15	2	10				1	35	37

cannot be used in the Niagaran and Wapsipinicon with any success as shown in table 2. Bar graphs were drawn but discarded because there was too much variation in one member and within zones in that member.

MINERALOGY OF INSOLUBLE RESIDUES

The following is a brief description of the relative correlative value and mode of occurrence of the dominant minerals of the residues in the order of their relative abundance. They are tabulated stratigraphically in table 3.

The *clay* minerals form the major constituent of most of the residues, but the petrographic microscope alone is not sufficient equipment to make a significant study of them. From identifications that were made, it was found that illite is by far the most common clay mineral and beidellite is often abundant. Nontronite and kaolinite are also present. No stratigraphic significance could be attached to such identifications as were made. The writer suggests that in future work the clay portion of the residue be decanted off because in most cases all it does is make more difficult the identification of the more significant minerals.

Quartz is found at all horizons in a majority of the samples. However, the form of its occurrence is also diverse and therein lies its correlative value. In detrital form it occurs in all shapes and with all degrees of frosting, but it is too widespread to be distinctive. In secondary form it occurs as euhedra, authigenic[1] grains, and aggregates of euhedra. Spherulites of chalcedony are included here because their origin is believed to be comparable to that of secondary quartz. In size, quartz has been found ranging from several millimeters down to the limit of recognition (about 1/256 millimeter).

Hematite seems to have little significance stratigraphically. This is also true of limonite and other hydrous iron oxides. Although usually occurring as very small irregular masses, hematite sometimes is found in the form of cubes and octohedrons, indicating pseudomorphism after pyrite. A few samples showed all gradations between it and pyrite.

The dominant *feldspar* is albite with microcline, adularia, and oligoclase present in minor quantities. More basic feldspars are extremely rare. The feldspars occur chiefly as euhedra, some of which are authigenic. There are minor quantities of cleavage and detrital grains. Feldspar is one of the best minerals for correlation in the Silurian and Devonian.

Gypsum occurs most commonly as flat flakes composed of interlocking crystals, as cleavage fragments, and as well-formed crystals, some of which are twinned. Crystals of gypsum formed by the reaction of the sulphuric acid in commercial hydrochloric acid can be distinguished because of their uniform small size (approximately 1/128 millimeter) and rhombic crystal form, but care in the digestion of the sample makes their occurrence rare.

Chert occurs commonly, but it is of practically no correlative value. It is found as nodules, concretions, ooloids, and detrital grains.

Pyrite is of small value stratigraphically, but it is surprisingly rare in the Gower and Wapsipinicon formations, especially in comparison with Ordovician and Mississippian limestones. It is found chiefly as cubes, octohedrons, pyritohedrons, crystalline masses, and nodules. Minor quantities of marcasite and chalcopyrite are also present.

The general term *asphaltum* is applied to a brownish-black, tar-like substance occurring in very small flakes or balls. It has a hardness of slightly less than one, a specific gravity of about 1.3, an index of refraction of 1.62, and was not dissolved by carbon tetrachloride. It is distinctive because it occurs only in the members of the Wapsipinicon formation.

Little attention was paid to the ac-

[1] Authigenic is here used to describe a secondary growth in which the optical orientation of the secondary growth is different from that of the nucleus.

cessory minerals, except to identify and record them when they were observed. In the following summary they are discussed in the order of their relative abundance. *Magnetite* was used as a "dump-box" term for any black or very dark colored, opaque mineral. Included here are at least hematite, ilmenite, and magnetite. Magnetite was found most abundantly in the Gower and Spring Grove, while the Kenwood and Coggan contained relatively the least quantity.

Zircon is also an abundant accessory and a few grains were found in a quarter of the samples. It is present chiefly as abraded grains and is found with practically the same frequency from the Hopkinton to the Cedar Valley.

Rutile is another ubiquitous mineral occurring with little variation in abundance throughout. It occurs as detrital grains and as well-formed, sometimes twinned, crystals. The trend is toward scarcity in the Otis, Coggan, and Davenport and abundance in the Hopkinton.

Opal is perhaps the best index mineral of the accessories as it was found abundantly in the Coggan, Otis, and Davenport, and not more than a single occurrence is recorded from the Hopkinton, Gower, Kenwood, Spring Grove, and Cedar Valley. It occurs as glass-like slivers and fragments. *Leucoxene* is found sparingly in all divisions. *Tourmaline* occurs chiefly in brownish-green to green crystals most of which have been abraded. A few rare brown and black specimens were observed. Several occurrences were noted from the Hopkinton but only single specimens were found in the Otis, Kenwood, and Davenport.

Glauconite is found rarely and diversely as an accessory, in the form of irregularly shaped flakes and as a pigment-like coating on clay particles. In rare samples, it makes up a notable percentage of the residue in the Hopkinton, Cedar Valley, and particularly the Otis.

Anatase occurs as crystals and crystalline masses that have a nearly equal distribution stratigraphically. The following minerals were found in less than three per cent of the samples: *anhydrite, apatite, biotite, chlorite, fluorite, garnet, hornblende, muscovite, siderite, sphalerite, titanite, topaz, tremolite,* and a *zeolite.*

SILURIAN SYSTEM

The Silurian rocks involved in this work, i.e., contact the Devonian somewhere in the outcrop area, are the Gower and Hopkinton dolomites of the Niagaran series. The Hopkinton consists of 180 feet at a maximum of medium-bedded to massive, buff dolomite with zones containing beds and nodules of white chert. The underlying Gower consists of buff to light gray dolomite up to 120 feet in thickness. In it are large bioherms with structureless interiors with flanking thin and medium-bedded dolomite beds dipping away from the center. These grade into horizontally bedded, non-reef dolomites. Occasional beds of white chert are present in the non-reef beds.

Insoluble residues.—The Hopkinton is comparatively high in insoluble material, ranging from 0.34 to 8.12 per cent insoluble, with an average of 2.92 and a mean of 1.66 per cent. Although there is considerable overlap with the amounts of residue in the Gower, it can sometimes be distinguished from the Gower on this basis alone as the Gower ranges from 0.06 to 2.28 per cent insoluble with an average of 0.60 and a mean of 0.44 per cent. In fact, the Gower has less insoluble residue than any of the beds studied, but this may be due partially to the fact that most of the samples were from the reef phase which is lower in impurities than the non-reef phase.

Feldspar is present in most of the Gower and Hopkinton samples and authigenic crystals are common. Gypsum and asphaltum were not found in any sample. These minerals are thus distinctive because feldspar is found very sparingly in the Coggan and numerous samples showed the presence of gypsum or asphaltum or both. Secondary quartz occurs rarely, but when present it usually makes up the bulk of the residue. In the Coggan above it does not make up

more than 10 per cent of any one residue. No spherulites of chalcedony were found in the Niagaran, but they are abundant in the Wapsipinicon, particularly the upper part. Pyrite and chert are rare in the Gower and common to abundant in the Hopkinton.

DEVONIAN SYSTEM

Wapsipinicon formation.—The first study of the lower part of the Devonian system in Iowa was made by Norton in 1894 and 1895 when he proposed the term "Wapsipinicon formation" for strata between the Silurian system and the Cedar Valley formation. He differentiated four members which in ascending order are Otis, Kenwood, Lower Davenport, and Upper Davenport. At the same time he differentiated the Bertram and Coggan dolomites and placed them in the Silurian. The Coggan was removed from the Silurian and placed in the Wapsipinicon in 1901, but in 1916 Norton demoted it to become a phase of the Otis. At this time the Bertram was also placed in the Devonian. This remained the standard Wapsipinicon section for Iowa until 1935 when Stainbrook removed the Upper Davenport to the Cedar Valley and changed the name Lower Davenport to Davenport. He also separated the upper beds of the Kenwood and called them the Spring Grove member. He revived the term Coggan for its original place as the lowest member of the Wapsipinicon and dropped Bertram as a correlative of the Otis.

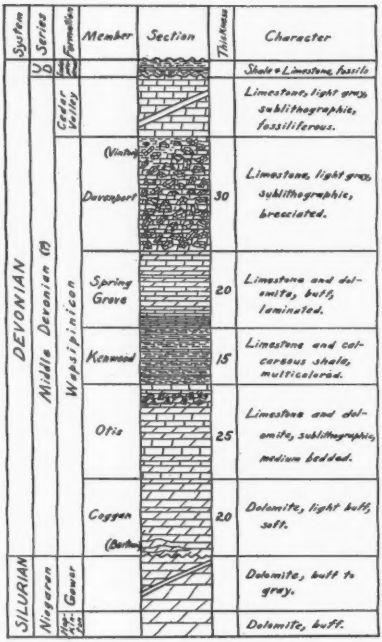

FIG. 1.—General columnar section of the Wapsipinicon and adjacent formations in Iowa.

Coggan member.—The Coggan member was named by Norton for about 20 feet of soft, magnesian limestone which is well-exposed at Coggan in Linn County. He tentatively placed it in the Silurian in 1895, but transferred it to the Wapsipinicon formation in 1901, mainly on the basis of its fossils. These fossils were *Spirifer subumbonus*, aff. *Dalmanites erina*, *Proteus* sp., and *Conocardium* sp. In 1916 he referred to these beds as the Coggan phase of the Otis because *S. subumbonus* occurs abundantly in both of them. Stainbrook returned the term Coggan to its original usage in 1935 when he used it to designate the lowest member of the Wapsipinicon.

The Coggan has one characteristic that distinguishes it from all other divisions of the geologic column in Iowa. Certain zones, both near the base and near the top, are filled with numerous external molds of a brachiopod only 1–3 millimeters long. These and a few rough casts show it to bear a close resemblance to the larger, so-called *Martinia* (*Spirifer*) *subumbona* of the Otis. They probably should be interpreted as evidence that the Coggan and Otis are very closely related in time and Coggan time may represent a "depauperate" opening stage in the evolution of that fossil.

The Coggan is a soft, buff dolomite

containing these small brachiopod molds in zones that are most numerous near the upper contact. No clear contacts between it and the Silurian are known in Linn County, but such sections are numerous in Cedar County. In a few places the Coggan contains small worm holes near the top. There is a weathered, oxidized, shaly zone between the Coggan and Otis that contains crystalline quartz as internal molds of these worm burrows. This shaly zone may represent a diastem or ground water action after consolidation.

The Bertram member of Norton is believed to be either a distinct member below the Coggan or part of the Coggan. It is a rather pure dolomite and this puts it more logically with the Coggan than with the Otis where it was placed by Stainbrook. Also, exposures of it are found below beds that are known to be Coggan. This dolomite is hard, dense, light gray to gray and is slightly brec-

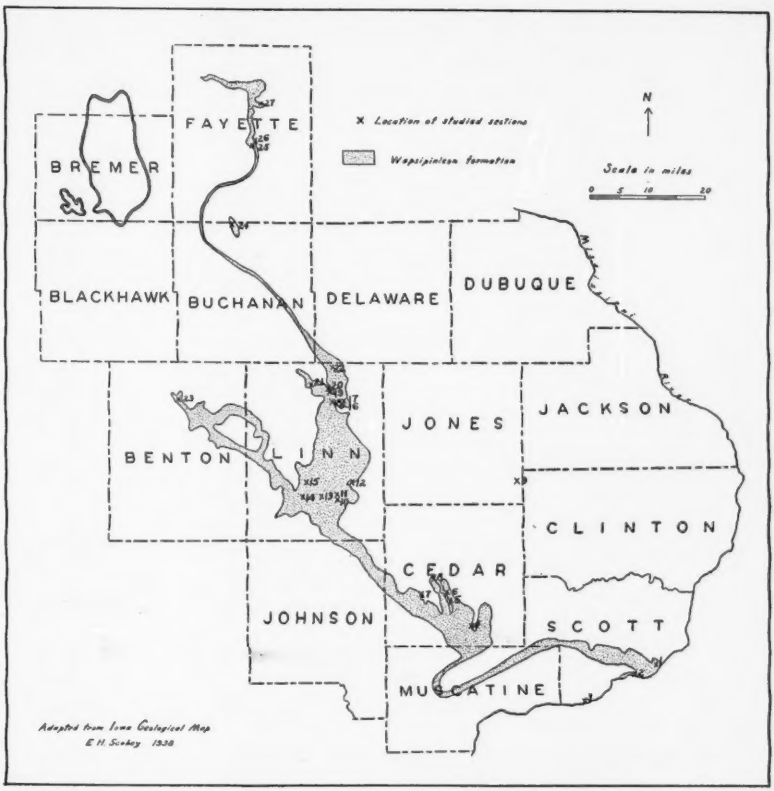

FIG. 2.—Areal geology map of the Wapsipinicon formation showing location of exposures from which samples were analyzed.

ciated in places. Since it is known only in a small area in south-central Linn County, and its residues are closely comparable with those of the Coggan, the Bertam is here considered a local phase of the Coggan.

Insoluble residues.—The Coggan is characteristically low in residue, ranging from 0.14 to 22.3 per cent and having an average of 2.63 and a mean of 0.67 per cent insoluble. Nearly all the samples that showed more than two per cent residue were found near the base of the member, and since the much larger residues are found just above the contact with the Gower, the percentage of insoluble material is a good criterion to follow in separating the Coggan from the Gower. The Bertram shows its relationship with the lower part of the Coggan by having a mean of 1.67 per cent insoluble.

The Coggan is very low in feldspar (none was found in Cedar County), which distinguishes it from the Silurian which has feldspar in nearly every sample. Asphaltum is present in one-fifth of the Coggan samples and is a good means of distinguishing the Wapsipinicon from the Niagaran as no asphaltum has been found in the Niagaran. Pyrite was not found to the extent of one per cent in a single one of the samples, but it is rare in the Niagaran and not very abundant in the Otis. Gypsum is rare in the Coggan of Cedar County and abundant in Linn County, but has not been noted in the Silurian. The Bertram of Linn County compares closely with the Coggan because it is very high in gypsum and has practically no feldspar.

Otis member.—The Otis was named by Norton in 1894 for 30 feet of lithographic limestone found along the Cedar, Buffalo, and Wapsipinicon rivers. In 1895, he designated several quarries in the vicinity of Otis (just east of Cedar Rapids) as the type locality.

The term Otis is applied to some thin to medium-bedded limestones and dolomites that occur between the Coggan and Kenwood members of the Wapsipinicon formation. Contrary to former belief, the Otis is not a pure limestone, but is composed of interbedded limestones and dolomites with the latter making up at least half of the bulk of the member. The rock is sublithographic to medium crystalline in texture, and most of it is light gray to light buff in color. Included in it are more coarsely crystalline blackish, purplish, and brownish beds, and lenses and crystals of calcite. In Cedar County, a zone containing discoidal masses of dark-colored chert is found about the middle of the member. These flattened nodules average about 6 inches in thickness and are laid end to end to form a nodular bed. Many of them contain large vesicles, some of which are partially filled with calcite. In many localities, there occurs near the base of the member a thin bed described in the field as a "calcite" bed. It is a resinous-brown bed up to 10 inches thick that breaks out in cleavage fragments as if it were composed of interlocking calcite crystals up to 2 inches in size. The Otis is commonly not brecciated, but in certain places, such as in western Cedar Rapids, it is finely brecciated in the upper part.

The only fossils found in this member are worm borings and a small brachiopod, identified by Stainbrook, as *Martinia subumbona*. The brachiopod occurs abundantly in a few localities in the lower part of the member. Worm borings about ½ to 1 mm. in diameter are commonly found near the base of the member and, although two occurrences were noted from the upper part of the Coggan, they seem to make a usable marker horizon.

This member has been recognized in Scott, Cedar, and Linn counties. It is not exposed north of Linn County and in Fayette County it has been cut out by overlap since the Spring Grove rests directly on the Silurian. It averages between 20 and 30 feet in thickness in the area of outcrop.

Insoluble residues.—The amount of residue in the Otis is quite variable, ranging from 0.10 to 23.3 per cent. The very

high percentages are due to an abundance of black chert at that horizon. It is lower in insoluble material than any other member of the Wapsipinicon having an average of 2.41 and a mean of 0.58 per cent.

The Otis residues are quite diverse mineralogically. Asphaltum was found in one-third of the samples. Secondary quartz is quite common and feldspar and pyrite are found in an average number of samples. Gypsum is rare, being found in only 10 per cent of the samples. The Otis is hard to separate mineralogically from the Coggan, but it seems to have slightly less gypsum and more asphaltum, pyrite and feldspar.

Kenwood member.—Although the name Kenwood had been used locally before, Norton first definitely named the Kenwood member in 1894 for some buff limestones and shales occurring between the Lower Davenport and Otis in Linn County. The type section should probably be considered as the exposure along Indian Creek in Kenwood Park in northern Cedar Rapids. At that time Norton correlated it with the Independence shale and said it should be used only as a local synonym. This conclusion he maintained. in 1916 when he dropped the term Kenwood as no longer being useful. Stainbrook revived the term because he believed that the Independence "differs faunally and lithologically and occupies a higher stratigraphic position." The writer considers the Kenwood to be a good member name because the Independence is believed to be Lime Creek in age and therefore occupies a much higher stratigraphic position.

The Kenwood member is composed chiefly of interbedded, thinly-laminated, impure limestones and shales. It cannot correctly be referred to as a shale because it averages only 25 per cent insoluble. It is multicolored, but is dominantly buff and blue-gray. At its base is a bluish shale that rests with a sharp lithologic break, but with no evidence of unconformability, on the Otis member. The maximum thickness of about 20 feet is attained around Cedar Rapids.

The writer has identified it with certainty only in Linn County. Both Norton and Stainbrook recognize it in Scott and Cedar counties, but if it is present, it at least is not shaly. This might well be the case because a small drop in the amount of argillaceous material would make it appear as a limestone. At least, it cannot be distinguished from the Otis.

Insoluble residues.—The Kenwood is from 3.21 to 85.7 per cent insoluble, with an average of 32.9 and a mean of 24.0 per cent insoluble. The samples of the Otis below with a high insoluble content are chiefly composed of chert while that of the Kenwood is predominantly clay.

There are not enough samples to show a really significant mineralogy, but those studied show little gypsum and no feldspar or asphaltum. If this holds true, the Kenwood can be distinguished from the Otis below and the Spring Grove above because the latter members contain considerable amounts of all three minerals. The Kenwood also has a considerable amount of hematite and an average amount of pyrite.

Spring Grove member.—The Spring Grove was named by Stainbrook for beds exposed along the Wapsipinicon River in Section 24, Spring Grove Township, Linn County. These beds had formerly been included as the upper portion of the Kenwood member. It is composed of thinly-laminated, thin to thick bedded, reddish to light buff dolomites and limestones up to 25 feet thick. It is partially brecciated in places in Linn County, but in some places it may be distinguished on this basis alone from the overlying Davenport which is often highly brecciated.

The Spring Grove was not recognized southeast of Linn County, although it may be represented by a changed facies. It is well developed to the north of Linn County, where it is present in the Vinton inlier and in the Fayette County exposures. In Fayette County, the Spring

Grove is filled with chert fragments and rounded quartz grains from underlying formations as it lies unconformably on the Silurian, overlapping the lower members of the Wapsipinicon and the Gower formation.

Stainbrook says it has unconformable relations with the Kenwood below and the Davenport above. There may be a slight diastem, but the evidence is not conclusive. At Kenwood Park in Cedar Rapids, the lower contact is gently undulating and the upper one involves a sharp change from non-brecciated to brecciated beds. At the Vinton inlier there is a sharp break of the same kind at the upper contact and this contact is also highly iron stained. At Fayette there is a thin, irregular, undulating shaly zone at the upper contact.

Insoluble residues.—With the exception of the Kenwood, the Spring Grove has the largest amount of insoluble residue of any member of the Wapsipinicon. It ranges from 0.10 to 12.40 per cent insoluble, with an average of 2.77 and a mean of 1.22 per cent insoluble. The amount of insoluble residue is variable both horizontally and vertically, the two extremes having been noted in one exposure. The largest residues, however, occur near the contact with the Kenwood. In only a few cases can it be distinguished from the Davenport above on the basis of percentage of residue, but it can usually be separated from the Kenwood on that basis.

The Spring Grove is high in secondary quartz, including spherulites of chalcedony, which closely relates it to the Davenport and distinguishes it from lower members and from the Silurian. It is also high in feldspar and chert and fairly high in gypsum, while asphaltum, pyrite and hematite are found in few of the samples. Although these latter minerals are found in the Kenwood and Davenport, they occur in different amounts and a series of several samples might show distinctions that would place them in or out of the Spring Grove.

Davenport member.—In 1894 Norton named the Upper Davenport and Lower Davenport for beds exposed in the vicinity of Davenport and placed them both in the Wapsipinicon formation. In 1935, Stainbrook placed the Upper Davenport in the Cedar Valley and changed the name of the Lower Davenport to Davenport. The Upper Davenport is very fossiliferous and closely related faunally to the rest of the Cedar Valley, while the Lower Davenport is unfossiliferous. The writer follows Stainbrook's definition chiefly because the changes from non-fossiliferous to fossiliferous beds is readily recognizable in the field.

The Davenport is recognized in exposures in Scott, Cedar, Linn, Benton, Buchanan, and Fayette counties. It is typically a gray, sublithographic, dense, unfossiliferous, pure limestone which is commonly highly brecciated. A complete description of these breccias was given by Norton in 1916. The member averages between 10 and 30 feet in thickness, and may be more than 50 feet thick in Scott County where the lower boundary cannot be delimited. It is dominantly a pure limestone although the matrix of some of the breccias is dolomitic in the northern area. It can be distinguished from the Spring Grove below because the Spring Grove contains beds of dolomite.

In Benton and Fayette counties, there is a shaly zone up to 15 feet thick that is made up of brecciated limestone and shale mixed. This shaly zone was originally called Kenwood (Independence) by Norton who interpreted the beds below it to be Otis and Coggan. Stainbrook correlated it with the Independence and called the beds below it Davenport and Spring Grove. The writer agrees with Stainbrook on the correlation with the Davenport and Spring Grove because a sample from the lower bed showed 25 per cent calcite and no Coggan samples were found to be that high in calcite. Twenty-four miles east at the type section of the Spring Grove samples from the upper and lower part of the member

show almost identical minerals in the insoluble residues as samples from the lower beds at the Vinton inlier (numbers 21 and 23 in table 3). The upper beds at the Vinton inlier are very highly brecciated from top to bottom which more closely allies them to the Davenport than the much less frequently brecciated Otis. No worm holes or brachiopod molds were found in the lower beds, and they are normally found in the Coggan.

The writer believes that the shaly zone just below the Cedar Valley is closely related to the Davenport and since it is unfossiliferous, its correlation with the Independence is highly questionable. Therefore, it is proposed to call this shaly bed the Vinton phase of the Davenport in order to distinguish a very local shale facies from an otherwise all limestone member.

Insoluble residues.—The Davenport (excluding the Vinton) has a range of 0.06 to 4.66 per cent insoluble, averaging 1.62 per cent and with a mean of 1.09 per cent insoluble. Although the Davenport insoluble residue averages slightly lower and does not have such a high range as that of the Spring Grove, it can rarely be distinguished from the Spring Grove on this basis. The Davenport also ranges and averages so much lower than the lower portion of the Cedar Valley that the two formations can usually be separated on this basis. The upper shaly portion of the Davenport that is referred to as the Vinton phase ranges from 18.15 to 25.30 per cent insoluble.

The Davenport is notably high in secondary quartz, which in many samples is made up dominantly of spherulites of chalcedony. It can be distinguished from the Cedar Valley on this basis and on the fact that it is also much higher in detrital quartz. It is low in feldspar and high in gypsum, particularly in the northern area (Benton, Buchanan, and Fayette counties). Asphaltum, hematite, and pyrite are found in an average number of samples. Asphaltum is particularly useful when found because it indicates Wapsipinicon as distinct from the Cedar Valley in which no asphaltum was noted.

Cedar Valley formation.—The Cedar Valley limestone was defined by McGee in 1891 to include all the Devonian below the Hackberry shale except the Independence. It was redefined by Norton in 1895 when he excluded the Wapsipinicon formation, including the Upper Davenport beds. This limestone was redefined again by Stainbook in 1935 when he placed the Upper Davenport in the Linwood member of the Cedar Valley formation.

The only part of the Cedar Valley included in the present study was the lower portion, or that in the Linwood member which lies conformably on the Wapsipinicon. It is a gray, sublithographic to finely crystalline limestone which is often brecciated, but never to the extent of the Davenport beds below. The Cedar Valley is a pure limestone in the southern area, but it becomes slightly dolomitic in the northern area and is reported as being a dolomite north of there. It is highly fossiliferous with corals, cephalopods and brachiopods predominating.

Insoluble residues.—The Cedar Valley is very high in amount of residue and can often be distinguished from the Davenport beneath on that basis alone. The limestone varies from 2.33 to 15.57 per cent insoluble, averaging 6.93 and with a mean of 7.79 per cent insoluble. This high insolubility is particularly distinctive because many of the samples have the same external lithologic appearance as the Davenport.

This division is notably low in both detrital and secondary quartz. Feldspar and gypsum are both present in average amounts. Asphaltum is absent and hematite is rare. Pyrite is more abundant than in any lower division. Thus, the rarity of hematite, abundance of pyrite, lack of asphaltum and comparative lack of quartz help to distinguish the lower portion of the Cedar Valley from the Wapsipinicon.

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